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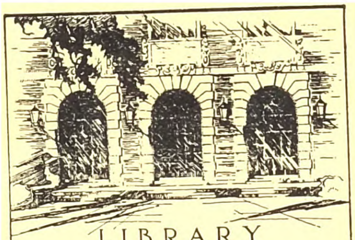

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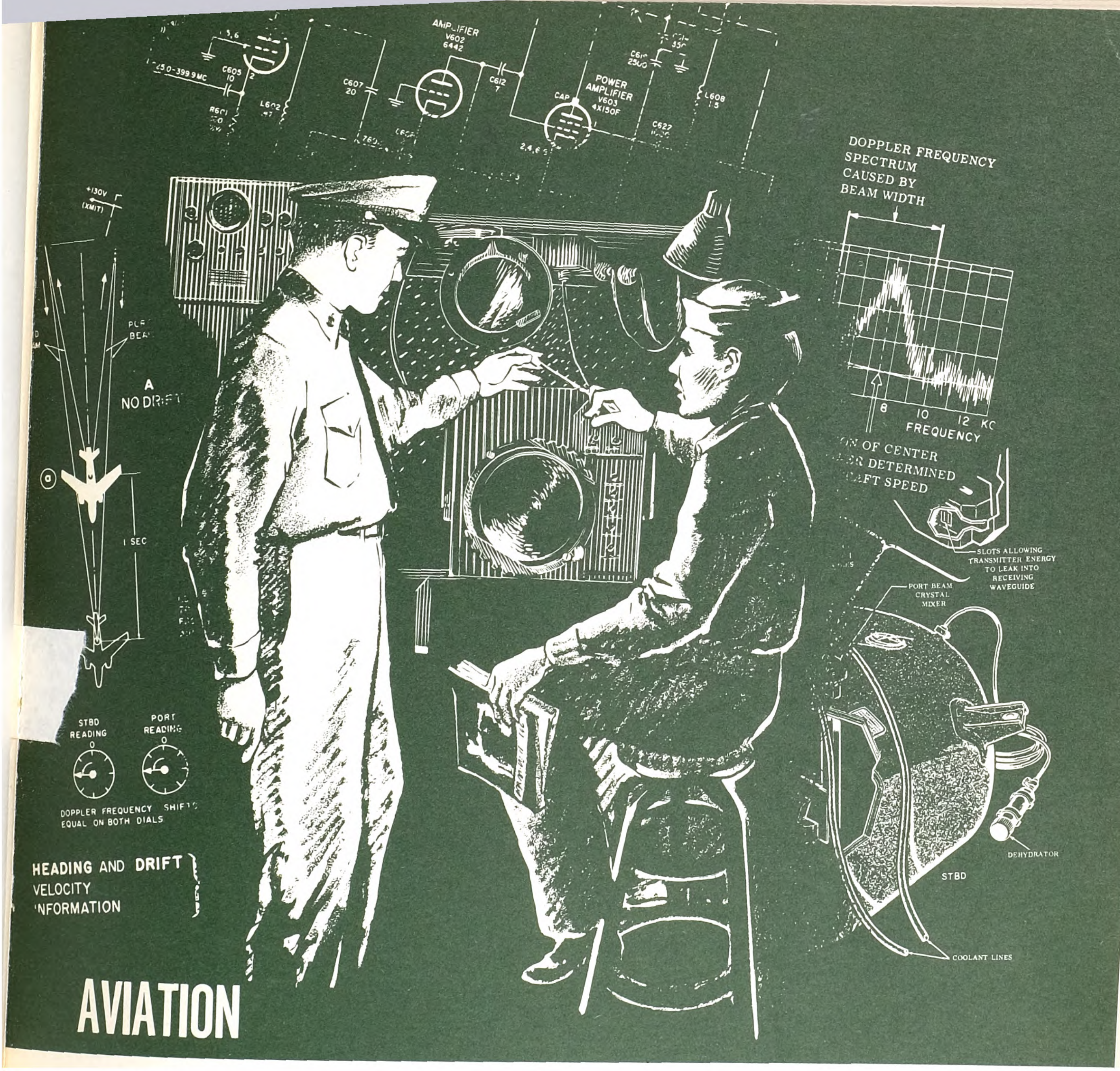

AVIATION
ELECTRONICS TECHNICIAN 1 & C

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSE NAVPERS 10318-A

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PREFACE

This Navy Training Course is one of a series of training courses prepared especially for enlisted personnel of the U. S. Navy and Naval Reserve who are preparing for advancement to AT1 and ATC. Since all personnel seeking advancement to these levels are held responsible for the entire contents of this training course, a study guide has not been included.

This training course is a revision of the course *AT 1 & C*, NavPers 10318, that was published in 1957. Approximately 60 percent of the material in this revision concerns subjects that were not covered in the original course. Chapters 1 and 2 are nontechnical in nature and relate to (1) the duties and responsibilities of senior petty officers and (2) supply and publications. The remaining 13 chapters relate to the technical aspects of the rating at the First Class and Chief levels.

Subject matter presented relates to RC and RL networks including transient and nonsinusoidal voltages, triangular waves, phase shifting, and resistance-capacitance oscillators; special circuits including limiters, clippers, d-c restorers, time-base and square wave generators, the blocking oscillator, counting circuits, AFC, and delay and marker systems; propagation of radio waves; waveguides and cavity resonators; UHF and microwave techniques including triode oscillators, magnetron oscillators, velocity-modulated tubes, and crystal mixers; UHF and microwave antennas; servomechanisms; transistorized circuitry along with a discussion of basic circuits, typical application of transistors, and servicing techniques; principles of television and its application to naval aviation; introduction to digital computers including terms, binary system of numbers, typical circuits, and applications; and electronic equipment, test equipment and maintenance techniques.

This training course, *Aviation Electronics Technician 1 & C*, NavPers 10318-A, has been prepared by the United States Navy Training Publications Center, Memphis, Tennessee, and the Training Division of the Bureau of Naval Personnel. Credit is also given to the Aviation Electronics Technician School, Memphis, Tennessee, for preparation of the end-of-chapter questions.

First edition 1957
Revised 1961

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ACTIVE DUTY ADVANCEMENT REQUIREMENTS

<table>
<tr><th>REQUIREMENTS *</th><th>E1 to E2</th><th>E2 to E3</th><th>E3 to E4</th><th>E4 to E5</th><th>E5 to E6</th><th>E6 to E7</th><th>† E7 to E8</th><th>‡ E8 to E9</th></tr>
<tr><td>SERVICE</td><td>4 mos. service—or completion of recruit training.</td><td>6 mos. as E-2.</td><td>6 mos. as E-3.</td><td>12 mos. as E-4.</td><td>24 mos. as E-5.</td><td>36 mos. as E-6.</td><td rowspan="2">48 mos. as E-7. 8 of 11 years total service must be enlisted. Must be permanent appointment.</td><td rowspan="2">24 mos. as E-8. 10 of 13 years total service must be enlisted.</td></tr>
<tr><td>SCHOOL</td><td>Recruit Training.</td><td></td><td>Class A for PR3, DT3, PT3.</td><td></td><td></td><td>Class B for AGCA, MUCA, MNCA.</td></tr>
<tr><td>PRACTICAL FACTORS</td><td>Locally prepared check-offs.</td><td colspan="7">Records of Practical Factors, NavPers 760, must be completed for E-3 and all PO advancements.</td></tr>
<tr><td>PERFORMANCE TEST</td><td colspan="2"></td><td colspan="4">Specified ratings must complete applicable performance tests before taking examinations.</td><td></td><td></td></tr>
<tr><td>ENLISTED PERFORMANCE EVALUATION</td><td colspan="2">As used by CO when approving advancement.</td><td colspan="6">Counts toward performance factor credit in advancement multiple.</td></tr>
<tr><td>EXAMINATIONS</td><td colspan="2">Locally prepared tests.</td><td colspan="4">Service-wide examinations required for all PO advancements.</td><td colspan="2">Service-wide, selection board, and physical.</td></tr>
<tr><td>NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)</td><td></td><td colspan="5">Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).</td><td colspan="2">Correspondence courses and recommended reading. See NavPers 10052 (current edition).</td></tr>
<tr><td rowspan="2">AUTHORIZATION</td><td colspan="2">Commanding Officer</td><td colspan="4">U.S. Naval Examining Center</td><td colspan="2">Bureau of Naval Personnel</td></tr>
<tr><td colspan="6">TARS are advanced to fill vacancies and must be approved by CNARESTRA.</td><td colspan="2"></td></tr>
</table>

* All advancements require commanding officer's recommendation.
† 2 years obligated service required.
‡ 3 years obligated service required.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
	FOR THESE DRILLS PER YEAR								
TOTAL TIME IN GRADE	48	6 mos.	6 mos.	15 mos.	18 mos.	24 mos.	36 mos.	48 mos.	24 mos.
	24	9 mos.	9 mos.	15 mos.	18 mos.	24 mos.	36 mos.	48 mos.	24 mos.
	NON-DRILLING	12 mos.	24 mos.	24 mos.	36 mos.	48 mos.	48 mos.		
DRILLS ATTENDED IN GRADE †	48	18	18	45	54	72	108	144	72
	24	16	16	27	32	42	64	85	32
TOTAL TRAINING DUTY IN GRADE †	48	14 days	14 days	14 days	14 days	28 days	42 days	56 days	28 days
	24	14 days	14 days	14 days	14 days	28 days	42 days	56 days	28 days
	NON-DRILLING	None	None	14 days	14 days	28 days	28 days		
PERFORMANCE TESTS		▨	▨	Specified ratings must complete applicable performance tests before taking examination.					
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 760, must be completed for all advancements.							
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.							
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.						Standard EXAM, Selection Board, and Physical.	
AUTHORIZATION		District commandant or CNARESTRA					Bureau of Naval Personnel		

* Recommendation by commanding officer required for all advancements.

† Active duty periods may be substituted for drills and training duty.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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The terms "fluxgate" and "gyro fluxgate" used in chapter 10 are registered trade names of the Bendix Corporation.

READING LIST

NAVY TRAINING COURSES

Basic Electricity, NavPers 10086-A
Basic Electronics, NavPers 10087 (current edition)
AT 3 & 2, NavPers 10317-A
Mathematics, Vol. 1, NavPers 10069-B
Mathematics, Vol. 2, NavPers 10070-A
Basic Hand Tool Skills, NavPers 10085
Basic Machines, NavPers 10624
Standard First Aid Training Course, NavPers 10081
U. S. Navy Safety Precautions, OpNav 34P1 (chapter 18)

USAFI TEXTS

For additional reading and study, the United States Armed Forces Institute (USAFI) courses are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

NUMBER	TITLE
C 164	Beginning Algebra I
C 165	Beginning Algebra II
C 188	Trigonometry
C 290	Physics I
C 291	Physics II

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

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CHAPTER 1

DUTIES AND RESPONSIBILITIES

As a part of the Navy's training program, this Navy Training Course is written for the purpose of aiding you to prepare for advancement in rating. In order to meet the requirements for advancement you must have gained a wide background of practical experience in the field of aviation electricity and electronics, and you must also possess a thorough knowledge of these subjects from the standpoint of theory. Your past years of naval experience have afforded you an opportunity to equip yourself with much of the knowledge and many of the skills that will be of valuable assistance as you progress in your naval work. You should become thoroughly familiar with the contents of the Navy Training Courses given in the preface of this course; for these are essentially prerequisites to the publication that you are now going to study.

ADVANCEMENT IN RATING

Advancing to AT1 or ATC means much more than an increase in pay and the acquiring of the privileges of a first class or chief petty officer. This step up the Navy ladder of success means that you must increase your knowledge and skills as they relate to your field. You must assume the responsibility of training men as they advance in the field of naval electronics. Also, it means that much of your time will be devoted to work of a supervisory nature, and in doing this you will be required to assume duties that are somewhat new. You will be required to make decisions; in many situations you will be in charge of the electronics department of an activity or squadron.

You should be able to perform all of the professional jobs that are required of an Aviation Electronics Technician. Unless you can perform these jobs you cannot expect to command the respect of your men and your officers. You must be able to lead, supervise, and train men; organize and administer electronics shops engaged in the maintenance and repair of electronic equipment; and stow, preserve, and account for supplies and spare parts.

There are several good reasons for advancing in rating. Some of these are primarily advantageous to the individual and others are primarily advantageous to the Navy.

You profit personally from the additional ability that you derive from the study and other efforts that you must make in order to advance. You are a better educated and trained man. It is a boost to your pride and morale to be able to do your job better and to understand more completely the various aspects of your rating. Also, it pays you monetarily. You have more means to support yourself and your family, thereby providing a higher standard of living. You have a feeling of accomplishment since you know that you are getting ahead in your chosen career field. By climbing farther up the leadership ladder, you are in a better position to lead and guide the efforts of others, watching them grow and develop into efficient workmen and finer individuals.

The Navy also profits as personnel advance in rating, since they can render greater benefit to their branch of military service. Personnel are better qualified and are able to perform their duties more efficiently; they can give better training to others, and they can more effectively discharge their increasing responsibilities in connection with the management functions of supervision. They move up to replace those who have been promoted or retired, thereby making room for the individual who wants to move into their position; that alone is good for the morale of all concerned. As a result, the Navy has better trained and happier personnel.

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Training Courses

Navy Training Courses are written to provide enlisted personnel with training information needed to qualify for advancement. They are organized in such manner that they may be used with a minimum of supervision. It is recognized that no book is a substitute for actual experience. However, many of the men who desire to advance in rating do not have the opportunity to work at their specific job and must depend on training courses as their source of information. For this reason, Navy Training Courses are designed as self-study texts with a maximum of illustrations and with the text written in readable and conversational style.

This Training Course

In the performance of practical work, proficiency comes with practice and experience, for which no book, however helpful, can be an adequate substitute. On the other hand, you will find, in preparing for the written examination, that no amount of proficiency in practical work can take the place of the knowledge on which you may be examined. This course has been prepared to assist you in acquiring the knowledge that you will need in order to pass the exam for advancement to AT1 and ATC. It is designed to give appropriate personnel the sort of self-study help that they need, especially in those cases where there is little opportunity for a well-conducted training program or little chance of attending a service school.

CONTENTS

There are 15 chapters in this training course. This chapter is an introduction to the course. It is nontechnical in nature and is for the purpose of introducing you to the course. It sets forth your duties as a senior petty officer, describes the types of assignments that you may expect to fill, and explains the meaning of the various qualifications that you must fulfill in order to advance in rating. It describes some of the publications that you should refer to when studying for advancement and lists some general suggestions for study. Squadron or activity organization is discussed, along with the various maintenance levels and the tasks that are to be accomplished at each level. Duties of the senior petty officer are discussed from the standpoints of the preparation and maintenance of logs, records, and reports; shop administration; and training the men under you.

The other chapters deal with the technical aspects of the rates of Aviation Electronics Technician, First Class and Chief. Chapter 2 deals with the problems and responsibilities that relate to supply on the shop level; it also discusses many of the publications with which you should be familiar. RC and RL networks are presented in chapter 3. It deals with transient and nonsinusoidal voltages; transient voltages in RC and RL circuits; triangular waves in RC and RL circuits; phase shifting; and resistance-capacitance oscillators. Chapters 4 and 5 are devoted to a discussion of special circuits. These include limiters and clippers, d-c restorers, time-base generators, square-wave generators, the blocking oscillator, counting circuits, automatic frequency control, delay systems, and marker systems.

The propagation of radio waves is presented in chapter 6. This discussion centers around the topics of electromagnetic fields in space, ionospheric variations, ground-and sky-wave propagation, frequency, antenna site, and radar range considerations. Chapter 7 presents information on the topics of waveguides and cavity resonators. Waveguides are discussed from the standpoints of theory, introducing fields into a waveguide, and bends, twists, joints and termination. The treatment of cavity resonators relates to the fields in a cavity, how the cavity is excited, and uses of cavities. The chapter ends with a discussion of duplexer systems along with a description of a complete waveguide system.

UHF and microwave techniques are discussed in chapter 8. First the advantages of high frequencies are given and then the frequency limitations of conventional oscillators are discussed. Also, triode oscillators, magnetron oscillators, velocity-modulated tubes, and crystal mixers are covered. Chapter 9 relates to the various types of UHF and microwave antennas. Various types of antenna arrays are explained and typical airborne antennas are described.

The applications of servomechanisms to aircraft electronic systems along with a discussion of (1) the components of a servomechanism system and (2) typical circuit functions are given in chapter 10. Transistorized circuitry is discussed in chapter 11. The chapter begins with a review of basic transistor circuits; typical applications of transistors to radio receivers and power supplies are given; transistor servicing techniques are presented; and applications to airborne equipment completes the chapter.

Chapter 12 is devoted to a discussion of the principles of television and of how television is being used in naval aviation. An introduction to digital computers is given in chapter 13. Information given relates to terms used, binary system of numbers, typical circuits, and applications of digital computers to airborne use. Chapters 14 and 15 relate to electronic equipment and related test equipment; special test equipment; and maintenance techniques.

Besides the chapters described above, the preliminary part of the course includes a reading list, study guide, table of contents, preface, and the credo. At the end of each chapter there is a quiz, which you should use in your review of the chapters. In the back part of the course you will find the answers to the quizzes and the qualifications for advancement in the Aviation Electronics Technician rating. Also, the course contains an index.

HOW TO USE THIS COURSE

Proper use of this training course will greatly aid you in preparing for advancement in rating to Aviation Electronics Technician, First Class and Chief. Some individuals may make the mistake of merely studying the answers to the end-of-chapter quizzes. The ones who do this will not obtain much benefit from the course. As the examination for advancement will contain questions not included in the end-of-chapter quizzes, the persons who study the text material thoroughly will find themselves better qualified to pass the examination.

Since you have advanced to Aviation Electronics Technician, Second Class or First Class, you may have already adopted a method for using course material similar to this. However, the following method will provide you with a procedure that will enable this course to be used to the best advantage.

When you begin studying this course, turn to the table of contents to learn the page number of the appendix that lists the "quals" requirements. Carefully study the qualifications required of the rate to which you are advancing. Also, remember that you are held responsible for the requirements of all rates below the rate to which you are advancing.

When you think you have mastered the material of a chapter, turn to the end-of-chapter quiz. Indicate your answers on a separate piece of paper. Then turn to the answers in the appendix and check your responses. If some of your answers are incorrect, there may be one of several reasons for it. You may not have studied the material that the text items cover sufficiently to master it. Another possibility is that you failed to read the test items carefully and completely. You should study again all the material covered by test items that you answered incorrectly due to lack of understanding or failure to master the subject matter.

NOTE: Ability to answer all the questions of all the quizzes does not necessarily mean that you have mastered all the subject matter. The quizzes will help you to review much of the material, but they are no substitute for mastery of the material page by page.

As you study the material in this training course, you will find it helpful to read other references on the subject. Some of the most important of these are included in the reading list in the front of this book.

In connection with reference material, you should become familiar with a BuPers publication titled *Training Publications for Advancement in Rating,* NavPers 10052. The NavPers number is followed by a letter suffix which indicates the date of publication; presently the latest issue is NavPers 10052-H. This publication is a bibliography of Navy Training Courses and other publications required or recommended for study by naval personnel who are preparing for advancement. Publications are listed for each rating and provide a working list of material for enlisted personnel to study in preparation for qualification in the duties of the various rate levels of that rating. Training courses marked by an asterisk must be completed for specific rate levels before you are eligible to take the advancement examination. It must be realized that, as indicated in the *Manual of Qualifications for Advancement in Rating,* NavPers 18068 (Revised), all higher pay grades listed in this booklet may be held responsible for the materials in the publications listed for the lower rates of that particular rating.

Since in many instances only pertinent sections of publications are listed in the *Training Publications for Advancement in Rating* the most effective use will be made of this booklet by

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concurrent reference to the Quals Manual. Here again, it must be assured that the latest change to the manual is being used.

Another publication with which you should become familiar is the *List of Training Manuals and Correspondence Courses*, NavPers 10061-(letter suffix). This publication is distributed to all ships and stations to inform them of the latest available training manuals and correspondence courses; it is revised semiannually (January and July). Publications listed include Navy Training Courses; Enlisted Correspondence Courses (*Aviation Electronics Technician 1 & C*, for example); Officer Textbooks; Officer Correspondence Courses, such as *Naval Orientation;* and Special Purpose Publications, such as study guides for various rates and ratings.

The Enlisted Correspondence Course is designed for individual study and is used to develop a knowledge of the Navy Training Course. Participation in the Correspondence Course Program is on a voluntary basis, since mandatory completion of Navy Training Courses may be accomplished by passing (1) either locally prepared and administered tests based on the subject matter of the Navy Training Courses or (2) Enlisted Correspondence Courses based on the Navy Training Courses.

Officer Texts and Officer Correspondence Courses are designed as self-study materials to assist officers in improving their professional qualifications and broadening their general knowledge of naval subjects. All officer courses are open to warrant officers and chief petty officers. Qualified enlisted personnel of lower rates are eligible if recommended by their commanding officers.

Application for training manuals and correspondence courses should be made through the local information and education (I and E) office.

MILITARY LEADER AND TECHNICAL SPECIALIST

As a Navy petty officer you are both a military leader and a technical specialist. In your work, of course, these two phases go together. As a petty officer, you have certain general or military duties; and as a specialist, you have certain professional or technical duties. And you are responsible for attaining proficiency in both phases of a petty officer's work. This course deals primarily with your specialist or technical (professional) duties. However, both type duties are discussed.

Military Duties

LEADERSHIP

Since you have been a petty officer for some time, you realize that more leadership is required of the higher rates. Not only are you required to have superior knowledge, but you are also required to have the ability to handle personnel. This ability increases in importance as you advance through the various rates as a petty officer. More and more your worth to the Navy will be judged on the basis of the amount of efficient work you obtain from your subordinates rather than how much of the actual work you do yourself. You will be required to perform the composite role of master technician, leader, supervisor, inspector, and instructor.

Leadership involves organizing the activities of group members toward the accomplishment of a given task. Successful leadership, like anything else, takes practice. Be willing to accept responsibility and you will find yourself enjoying responsibility. Make yourself a leader your men will gladly follow. From their respectful attitude toward you, you will get a strong sense of satisfaction.

Much of what is presented in subsequent paragraphs is written in terms of shop supervision; this information applies equally to leadership. In fact, supervision is an aspect of leadership. It is the technique by which you intelligently guide the activities of your men.

Good organization provides the structure through which plans are formulated, clear cut lines of communication are established, authority and responsibility are delegated, quality and quantity of work are achieved, materials are procured, and missions are accomplished. The organizational structure in which you function depends on the type of duty to which you are assigned.

No matter what the type of organizationa structure, the senior AT should know the following:

1. To whom you and your men are directl responsible.
2. Where you can go for advice and assistance.
3. Where your orders and assignments originate.

4. Exactly what your superiors expect from you.
5. Just what your men and equipment are capable of doing.

As a supervisor you will occupy an important position in the maintenance department of your activity or squadron. You will be the link in the chain of command between your officers and your men. Consequently, you must be thoroughly familiar with the organization of your activity or squadron.

SUPERVISORY TECHNIQUES

Discipline

As a leading AT, it is your responsibility to organize your shop and men so that the tasks of the electronics shop can be accomplished with speed and accuracy. The duties and responsibilities of each man are spelled out in detail within a good organization. Each man knows exactly what is expected of him. However, you know from past experience that the mere listing of duties does not necessarily get the job done.

The established routine of work activity must be reinforced by discipline. The leading AT's problems of supervision and maintenance of discipline are complicated because in this category you are dealing with human beings and not the inanimate mechanical or electrical components of a piece of equipment. This means that you must supervise in a calm and understanding manner to get prompt and willing compliance with orders. You will command more respect and get better results by being reasonable and fair. Fairness is not to be confused with laxity or undue leniency.

Routine Procedure

Be certain that your men know what is expected of them. You can not expect anyone to do a satisfactory job unless his instructions are clear. You should have a standard operating procedure for all routine tasks. Have all of the men learn these procedures thoroughly. In certain complex or dangerous operations no deviation from the standard procedure should be permitted. However, if a man can perform his work satisfactorily by a method different from yours, and if his method is at least as fast, safe, and efficient, let him do the job his way. In fact, you will be wise to encourage any suggestions which might improve the quantity, quality, safety, or economy of the work.

In scheduling your work, remember that your men will need occasional breaks and periods of relaxation. If the factor of fatigue is not taken into consideration, work will fall behind schedule. On the other hand, if you grant an excessive number of breaks, you may lose control over your men. You must strive for a happy medium in each situation, and be flexible enough to allow for changing conditions. Make the standards of conduct consistent for everyone working under your supervision. Favoritism should never be shown.

Praise and Censure

There is a common misconception that discipline is merely a matter of administering censure or punishment. Discipline also has its positive aspects that all too often are overlooked. When inspecting the quality of work done by your men, you must resist the tendency to comment only on the mistakes that are made. You should comment favorably on the outstanding aspects of the job as well. Here too, you must use good judgment. No one is entitled to extra praise for doing a job well because that is his job. Nevertheless, proper comment goes a long way in boosting morale. However, excessive flattery should be avoided.

When your superiors comment favorably about work performed in your division, the information should be passed on to the men who helped earn the commendation. Do not leave the impression that you are due all of the credit. Another good rule to remember is PRAISE IN PUBLIC, CENSURE IN PRIVATE. When censure is necessary, be careful that the man understands why he is being censured. Be especially careful to avoid the use of sarcasm. If one of your men makes a mistake do not lose your temper. This NEVER does any good. If a man has misunderstood an order, a technique, or a principle, take steps to insure that future directions are given more clearly.

Personnel Relationships

True discipline is obtained through the voluntary cooperation of the men with their

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leader. It should be recognized that cooperation is a two-way proposition. The men depend on the leader to fulfill many of their psychological needs. They look to the leader for the security of his approval. They want a supervisor whom they can respect and brag about, and you, as the leading AT, want a crew that will be a credit to you, the AT shop, and the Navy. The relationship that you establish with your men is a reflection of your attitude toward them. If you know and understand them, have respect for their dignity as human beings, and show a sincere interest in their welfare, they will respond with renewed energy and with pride and confidence in your leadership. They will work because they want to and not because they are compelled to or because they fear punishment. This is what is meant by voluntary discipline. It is based on knowledge, reason, sense of duty, and loyalty, and is closely related to morale.

You should learn all you can about each member of your crew (their names, ambitions, problems, capabilities, and limitations). The men should know that you are sincerely interested in their welfare. Usually you should not volunteer advice on personal problems. However, a man with such problems often needs someone whom he respects to talk to. By simply being an understanding listener, it is possible to be of great help in such circumstances.

The men should be given an opportunity to get to know their leader. In this way a common ground of understanding is established. When work is to be done, you should be in the area. Your presence indicates that you know what is going on and are interested in what the men are are doing. Except in emergencies, you should tell the men what to do rather than how to do it. In this way they will learn by doing.

You should be a good craftsman, and your skill must be reflected in the high quality of your own workmanship. In fact, your work should set the example for others. Keep up with every new development, military and civilian, that might affect your work. If you are confronted with a question you cannot answer, admit it. No one person knows all the answers, so do not try to bluff. If the bluff does not work, you will lose the respect of your men. Instead, show your men that you have an inquiring mind. Make every effort to find the answer to the question and then share your knowledge with others in the shop. You will find that discipline becomes much easier if you show proficiency in your technical specialty.

As a first class or chief, you will frequently become involved in personnel problems, such as recommending men for promotion, and settling differences and grievances between them. You must handle such matters with discretion and fairness. Your job will put you in the role of a liaision man, for you will have to deal with equals and superiors as well as subordinates. Your attitude toward this chain of command is important since the whole structure of naval service is built upon ascending and descending responsibilities. Each officer and man in the Navy is dependent upon others for the smooth performance of his tasks.

The morale of men under you is an index to the efficiency of your shop. Attempt to detect small problems before they grow into large ones. Counsel with your men, give them advice and assistance whenever possible.

Professional Duties

The AT rating is a group of jobs which require essentially the same aptitudes, training, experience, skills, and abilities. Your professional (technical) duties include those jobs which require you to use your special training relating to a particular field. As an AT, your professional duties relate to those jobs that must be performed in maintaining and operating aircraft electronic equipment.

The rating of Aviation Electronics Technician is divided into six rates. The degree of complexity that the AT must face in connection with a job is determined by his rate. The higher the rate the greater the amount of responsibility that goes with the jobs required of the particular rate. Appendix X of this training course is a detailed listing by rate of the jobs that AT's are required to perform.

The petty officer level of chief is now divided into three pay grades—E-7, E-8, and E-9. This should serve as a considerable incentive to the men of the rating, since a person need no longer feel that he has reached the highest step of his enlisted career when he has advanced in rating to chief.

By now you should be thoroughly acquainted with the technical skills required of the Aviation Electronics Technician, Third Class and Second Class. The most important additional skills required of you as a first class or chief are as follows:

1. Organize and administer a safety program applicable to aviation electronic equipment and facilities; interpret and implement directives and instructions on safety precautions; inspect work areas, tools, and equipment to detect potentially hazardous and unsafe conditions and take appropriate corrective action.

2. Make qualitative performance tests of aircraft electronic systems; supervise and direct electronics line and hangar maintenance; evaluate and analyze reports of discrepancies and malfunctions in aircraft electronic systems and determine corrective action; evaluate performance of overhauled or newly installed aircraft electronic equipment; screen defective exchangeable components for feasibility of local repair; review and evaluate completed inspection forms, work orders, and failure and discrepancy reports.

3. Know the procedures for repairing printed circuits and techniques for testing transistor circuits; sources of electrical noise interference and methods of control; effects of environmental conditions upon operation of electronic and electrical equipment.

4. Repair and adjust automatic channel selecting and automatic tuning assemblies; test and adjust TACAN beacon simulators.

5. Know procedures for plotting deviation curves for aircraft ADF configuration; communication antenna theory; characteristics of induction field, radiation field, sky wave, ground wave, ground-reflected wave, ionospheric reflecting layers, skip distance, and maximum usable frequency and their effects on communications.

6. Test transmitter pulse transformer, pulse forming network, and modulator; install magnetron and thyratron tubes; perform spectrum analysis; measure ground position stabilization resolver response and check for correct solution to simulated relative motion problems.

7. Know the effects of various combinations of beam width, pulse length, pulse repetition frequency, scan rate, and power output relative to performance and applications of radar equipment; and principles of MAD equipment compensation.

8. Know operating principles of direction and attitude sensing elements, including gyros, compasses, and accelerometers; principles and and applications of limiter, clamper, counter, and discriminator circuits; principles of sweep generators, gated amplifiers, and timing circuits; microwave techniques and operating principles of waveguides, cavities, crystal mixers, and transmission lines; principles and applications of saturable core reactors and magnetic amplifiers; principles of impedance matching networks and devices; characteristics of readout methods used with analog and digital computing systems; principles of infrared detection; operating principles of microwave antennas, dish reflectors, and associated RF feeds and parasitic reflectors and directors.

9. Analyze tests and measurements to be made on electronic equipment and determine most appropriate test equipment to use; analyze test equipment defects and determine corrective action.

10. Know procedures for obtaining repair and calibration of test equipment; electronics test methods and practices.

11. Interpret mechanical, electrical, and electronic schematics and drawings and make simplified versions; use handbooks of maintenance and service instructions to determine performance specifications for making adjustments to aircraft electronic equipment.

12. Identify electronics parts by nomenclature and stock number and prepare supply requisition to obtain replacement; use NavAer *Publications Index*, to locate, identify, and obtain technical publications, directives and manuals; identify and order tools, equipment, and material; maintain custody records and conduct inventories; supervise the use, filing, and maintenance of publications, logs, and records; organize and supervise facilities for repair and maintenance of aircraft electronic equipment; maintain aircraft electronics configuration and status records; supervise inspection procedures to insure that applicable technical specifications and standards of workmanship are met.

13. Know standard organization and maintenance procedures of aircraft squadrons and maintenance activities; types and purposes of FUR's; types of information contained in aeronautical technical publications pertaining to aircraft electronic material and equipment; interpretation of source codes in parts catalogs; procedures for surveying accountable materials.

Your ability to perform the above listed skills is determined by a number of factors. The most important of these factors is the

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knowledge that you possess concerning a particular skill that you must perform. Navy Training Courses contain the information necessary for you to gain the knowledge in order to perform many of the technical duties of your rate. Insofar as possible, this training course, *AT1 & C*, contains information required of the First Class and Chief Aviation Electronics Technician.

QUALIFICATIONS FOR ADVANCEMENT

The *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised), is of vital interest to the division officer and the enlisted man alike. This publication is the official manual which promulgates the minimum qualifications for the advancement in rating of enlisted personnel in the Regular Navy and the Naval Reserve. It covers in more or less broad terms both the military and the professional requirements for advancement in all ratings in the Navy. The Bureau of Naval Personnel issues CHANGES to the Quals Manual in order to keep the requirements of your rating up to date. The qualifications printed in appendix X of this training course for the Aviation Electronics Technician rating are current through change 16 only. It is important that you refer to the latest change to the Quals Manual when preparing for any advancement examination. This is the only way you can be certain that you are studying all of the requirements of your rating. Visit your information and education office or consult your education and training officer for information concerning the latest changes to the manual.

The naval rating structure is subject to continual review to insure the most effective manpower utilization and career patterns. Beginning with change 11, two different and distinct rating structures exist in the Quals Manual. These are the structures established in 1947 and a new structure established in 1957. The older structure will be replaced by the new structure on an evolutionary basis with ratings revised in terms of the new structure as rapidly as possible. It is suggested that you study the preface of the Quals Manual since it sets forth in detail the aspects of the two structures. The AT rating structure has just recently been converted to the new structure and these new quals are included in this book as appendix X. Even though AT quals that follow the new structure have already been approved and published, it is felt that an understanding of why this change has been made will be beneficial. Following is a brief description of the two structures.

The 1947 structure provides for GENERAL SERVICE RATINGS and EMERGENCY SERVICE RATINGS. The general service ratings, which are for enlisted personnel of the Regular Navy in time of peace, provide for a petty officer broadly qualified in all aspects of his rating. The emergency service ratings, which are for personnel of the Naval Reserve in peacetime and for both the Regular Navy and the Naval Reserve in wartime, provide the flexibility needed to permit expansion from the broad general service areas to the narrower service areas within the same occupational grouping.

In recent years the rapid introduction of complex technological developments in the Navy, as well as greater use of noncareer personnel, has produced a need for modifications to the 1947 structure. A structure is needed which will provide for specialization and reduce training time. The concept of the broadly trained and qualified petty officer is retained in the new structure and, at the same time, effective manpower utilization is insured by providing desirable specialization in the lower pay grades of certain ratings. Also, this new structure applies equally to both the Regular Navy and the Naval Reserve and there is no change in an enlisted man's rating in the case of mobilization. The new structure consists of (1) GENERAL RATINGS (2) SERVICE RATINGS, and (3) EMERGENCY RATINGS.

A general rating reflects qualifications in all aspects of an occupational field and insures broadly qualified senior petty officers. It is similar to and will replace the present general service rating and is applicable to both the Regular Navy and the Naval Reserve. A service rating reflects qualifications in some of the aspects of an occupational field and provides specialization where deemed desirable. It is similar to and replaces the emergency service ratings for the Naval Reserve and also it is applicable to the Regular Navy. An emergency rating reflects qualification in a civilian skill which is not identified in the peacetime Navy but is required to be identified in wartime. It is similar to and will replace the exclusive emergency service rating.

In summary, the new rating structure wil provide (1) a completely integrated system applicable to both peacetime and wartime which undergoes no basic change in structure durin mobilization, and (2) a structure with inherent incentives to provide necessary generalization at the senior pay grades and built-in flexibility to accommodate specialization in the lower pay grades where necessary.

Military Requirements

The military requirements that are required of you are listed in appendix X of this training course. These are taken from the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised). Military requirements are applicable to all enlisted men irrespective of rating. Three Navy Training Courses have been written which cover all of these requirements. They are *Basic Military Requirements*, NavPers 10054, *Military Requirements Petty Officer 3 and 2*, NavPers 10056, and *Military Requirements Petty Officer 1 and C*, NavPers 10057.

The basic course is written to cover the military requirements of the first three pay grades. It is concerned primarily with the meaning of military requirements, naval organization, military drill and ceremony, security, ABC warfare, naval aircraft, service records, and advancement and training.

Military Requirements Petty Officer 3 and 2 is concerned primarily with the knowledge that a petty officer must possess in order to work independently and to assume leadership duties. Major topics covered are—importance of the U. S. Navy, naval career opportunities, military command and leadership, discipline and regulations, survival, communications, and training methods.

Military Requirements Petty Officer 1 and C is written for the senior petty officer and is concerned with the knowledge necessary to become a successful leader. Since you are preparing for advancement to first class or chief, you should become thoroughly familiar with the contents of this course. Also, you are responsible for the material in the other two courses. This course sets forth the military requirements of senior petty officers. It presents inspirational material concerning your place in the Navy. It points out your responsibilities as an instructor, describes some proven teaching methods that you may use, and presents techniques that may be used in evaluating your men. The last two chapters of this course are devoted to leadership. They contain a listing of the "do's and don'ts" of leadership and give examples of leadership problems that are apt to arise and methods of solving them.

Professional Requirements

The professional requirements required are listed in appendix X of this training course. These are taken from the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised) and are current through change 16. These are the professional (technical) qualifications required of Aviation Electronics Technicians to perform properly the duties of their particular rate. The most important of these requirements for the First Class and Chief Aviation Electronics Technician are discussed in this chapter under the heading Professional Duties.

This training course (*AT 1 & C*) is written primarily to aid the AT1 and ATC in fulfilling his professional requirements. Three additional training courses that relate to your professional requirements and with which you should become thoroughly familiar are—*Basic Electricity*, NavPers 10086-A, *Basic Electronics*, NavPers 10087, and *AT 3 & 2*, NavPers 10317-A.

Record of Practical Factors

Practical factors are those skilled operations that you must be able to perform prior to your advancement. These are given in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised). They are also included in appendix X of this training course. The requirements listed under practical factors include the minimum skills and abilities that you should possess in order to advance.

Form NavPers 760(AT), *Record of Practical Factors*, lists the practical factor (military and professional) requirements for the Aviation Electronics Technician rating. There is a similar form for all ratings. As you demonstrate proficiency in the required practical factors listed on this form, an entry is made which shows the date and the initials of the supervising officer. Instructions for completing this form are provided at the top of its first page.

Each man studying for advancement in rating should have a copy of this form for his personal record and guidance. A copy of this form is held by the division officer or other appropriate

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supervising officer for each man in pay grade E-3 through E-8. Upon transfer of an enlisted man, the supervising officer's copy of the form is signed, inserted in the correspondence side of the service record, and forwarded.

The appropriate items on NavPers Form 760(AT) must be completed before you are eligible to take the examination for advancement in rating. A few days prior to your advancement examination, you should check to see that the supervising officer's copy of your form 760 is or will be completed on time. Also, when you are being transferred to a new duty assignment you should check to see that all of the practical factors you have completed have been entered on your form 760.

Any major changes to the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised), require that the Record of Practical Factors form be reprinted. However, minor changes to the Quals Manual may be recorded in spaces provided in the form 760. The relationship between the Quals Manual and the form 760 is apparent, since the practical factor requirements printed in the form 760 are taken directly from the manual. Form 760 affords an orderly and meaningful method of recording your progress in advancement towards the next higher rate within the rating.

MAINTENANCE ORGANIZATION

As an Aviation Electronics Technician, First Class or Chief, you will most likely be assigned to a billet that relates directly to the operation and maintenance of aircraft electronic equipment. Because of your past naval experience, you already know that your assignment possibilities cover a wide range of duties and responsibilities. The most common command billets to which AT's are assigned are operating squadrons, naval air stations, aircraft carriers or seaplane tenders, or a training billet in a technical school. Each of the foregoing command billets will assign you to specific duties within the command. Depending on the type command, you can expect certain types of duties within each.

In operating squadron and seaplane tender billets, you will most likely perform routine electronics maintenance or be a member of a flight crew. On an aircraft carrier, your job will consist mainly of providing and maintaining shop facilities for the testing and repairing of airborne electronic equipment. In a naval air station billet, your job possibilities are more varied. In most cases, however, you will either maintain aircraft assigned to the NAS, or work in an O and R department. When assigned to a training billet, you will most likely be an instructor, technical writer, or work in a testing section.

A more complete description of the functions of each type of command billet is given in chapter 1 of *AT 3 & 2*, NavPers 10317-A.

The maintenance organization of a squadron or activity is under the direction of a maintenance officer. As head of the maintenance department, he exercises administrative control over the department and is responsible to the commanding officer for the accomplishment of its mission. He establishes procedures and delegates authority to subordinates. He provides for review of decisions and actions of his subordinates and controls assignments of personnel to divisions within the department. Each maintenance department will have an assistant head of the department. He implements the instructions and policies of the maintenance officer and acts for him in his absence.

In the organizational structures for aircraft maintenance departments that follow, as shown later in figures 1-1 and 1-2, each maintenance activity or squadron is shown as being assigned definite levels of maintenance responsibility; that is, class B and C, and class D, E, and F It must be borne in mind that the maintenance levels given here are only for the genera structure, and that each activity is individually assigned the level of maintenance it may perform. One NAS, for instance, may be a clas B and C maintenance activity, while another ma be designated class C and D.

Levels of Maintenance

CLASS C AND D MAINTENANCE (INTERMEDIATE)

This degree of maintenance is performed b designated maintenance activities for direct su port of using organizations. Its phases normal consist of calibration, repair or replacement damaged or unserviceable parts, components assemblies; the emergency manufacture of no available parts; and the providing of technic assistance to using organizations. Intermedia maintenance is normally accomplished in fixed or mobile shops, tenders, or shore repair facilities.

Class C Maintenance (Shop/Repair)

These processes involve the maintenance of operational aircraft (including guided missiles), aircraft equipment, and aircraft support equipment to insure that damaged or defective parts, subassemblies, assemblies, units, groups or sets removed from, or received for installation in, aircraft or equipment are restored to such a condition that they are ready and safe for continued service.

Class C maintenance is performed on parts, subassemblies, assemblies, units, groups and sets normally located in fixed ship or shore or mobile shops. It is performed without removal of aircraft or equipment from an operating or flight schedule unless prevented by insufficient quantities of available spare parts, subassemblies, assemblies, units, groups or sets. It is performed only by activities assigned the mission, task or function of providing such maintenance support to activities assigned aircraft or equipment. It is performed with authorized and qualified Shop/Repair maintenance personnel, using approved and authorized class C maintenance material.

Class C maintenance includes preservation, inspection, examination, and specified bench test of parts, subassemblies, assemblies, units, groups and sets removed from aircraft and aircraft support equipment. Correction of discrepancies and compliances with applicable instructions by calibration, repair and/or replacement of internally installed parts (requiring major but not complete disassembly), subassemblies, assemblies, units, groups or sets are considered class C maintenance.

Repairs of complete aircraft or equipment requiring complete disassembly are NOT class C maintenance. Even though this work may be performed in fixed ship or shore or mobile shops, such repairs are considered class B maintenance.

Class D Maintenance (Shop)

These processes involve the maintenance of operational aircraft (including guided missiles) aircraft equipment and aircraft support equipment to insure that parts, subassemblies, assemblies, units, groups or sets removed from, or received for installation in, aircraft, aircraft equipment, and support equipment are ready and safe for continued service. Class D Maintenance is performed on parts, subassemblies, assemblies, units, groups and sets normally located in fixed ship or shore or mobile shops. It is performed without removal of aircraft or equipment from an operating or flight schedule unless prevented by insufficient quantities of available spare parts, subassemblies, assemblies, units, groups or sets. It is performed by all activities that are assigned the mission, task or function of providing direct maintenance support to activities that are assigned aircraft or equipment. Only certain specified activities perform this support for their own assigned aircraft and equipment. This maintenance is performed by authorized and qualified shop maintenance personnel, using approved and authorized class D maintenance material.

Class D maintenance normally includes preservation, inspection, examination, and specified bench test of parts, subassemblies, assemblies, units, groups and sets removed from aircraft, aircraft equipment, and aircraft support equipment. Correction of discrepancies and compliance with applicable instructions by adjustment, minor repair and/or replacement of externally installed (requiring only minor disassembly) parts, subassemblies, assemblies, units, groups, or sets are considered class D maintenance. Repairs beyond the scope of minor repairs are not class D maintenance. Even though this work may be performed in fixed ship or shore or mobile shops, it is considered class C Maintenance. The emergency manufacture of parts requiring only portable hand and machine tools and semiportable or bench mounted equipment is within the scope of class D maintenance.

CLASS E AND F MAINTENANCE (ORGANIZATIONAL)

This degree of maintenance is performed by a using organization on its assigned equipment. The phases normally consist of inspecting, servicing, lubricating, adjusting and replacement of parts, minor assemblies and subassemblies.

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Class E Maintenance (Hangar Maintenance)

These processes involve the preventive maintenance of operational aircraft (including guided missiles), aircraft equipment, and aircraft support equipment to insure that an aircraft or equipment is ready and safe for continued service in any type of flight or operation for which it is designed and configured.

Class E Maintenance is performed on or in aircraft or equipments, which are normally located in a hangar, on a hangar deck or on or in a dock. It is performed during maintenance availabilities, with the aircraft or equipment removed from the operating or flight schedule. It is performed by all activities assigned operating aircraft or equipment, with authorized and qualified hangar maintenance personnel, using approved and authorized class E maintenance material.

Class E maintenance includes all intermediate and major inspections, and specified special and preservation inspections. It also includes functional test of aircraft, aircraft equipment and aircraft support equipment syscomtems. Correction of discrepancies and compliance with applicable instructions by adjustments, minor repair and/or replacement of installed parts, subassemblies, assemblies, units, groups or sets are considered class E maintenance. It does not include work on parts, subassemblies, assemblies, units, groups, or sets removed from aircraft or equipment. Such work is considered class D maintenance even though it may be performed in a hangar, on a hangar deck or on or in a dock.

Class F Maintenance (Line)

These processes involve insuring that operational aircraft (including guided missiles), aircraft equipment and aircraft support equipment are ready and safe for the type of flight or operation for which they are scheduled. Class F maintenance is performed on or in an aircraft or on equipment, which is normally located on a flight line, flight deck, launcher, ramp, or at a buoy, boom or mast. It is performed during maintenance availabilities, prior to, or between scheduled operations or flight, without removal of the aircraft or equipment from the operating or flight schedule. It is performed by all activities assigned or having physical custody of aircraft or equipment, by authorized and qualified line maintenance personnel, using authorized and approved class F maintenance material.

Class F maintenance includes servicing, daily and preflight or pre-operation inspections, ground tests, and troubleshooting aircraft, aircraft equipment, and aircraft maintenance support equipment systems. Correction of minor discrepancies and compliance with applicable instructions by adjustments and replacement of parts is within the scope of class F maintenance. It includes replacement of only those parts which do not require removal of units, assemblies and subassemblies. Removal of units, assemblies and subassemblies shall be considered Class E maintenance even though such work may be performed on the flight line, flight deck, launcher, ramp, or at a buoy, boom, or mast.

Supporting Activity

The aircraft maintenance department of a supporting activity has the mission of suppor of operating squadrons, including itself if i has aircraft assigned to it. It provides fo maintenance at the B and C levels.

Figure 1-1 shows the standard organizatio structure for a support activity and for a self supported squadron. Nomenclature and codin used are as follows.

All major segments of the organization reporting directly to the aircraft maintenance o ficer or his assistant shall be called division Divisions shall be subdivided into branche Coding has been established for identification all work segments of the organization.

The following codes and titles are used f the organizational segments through the bran level.

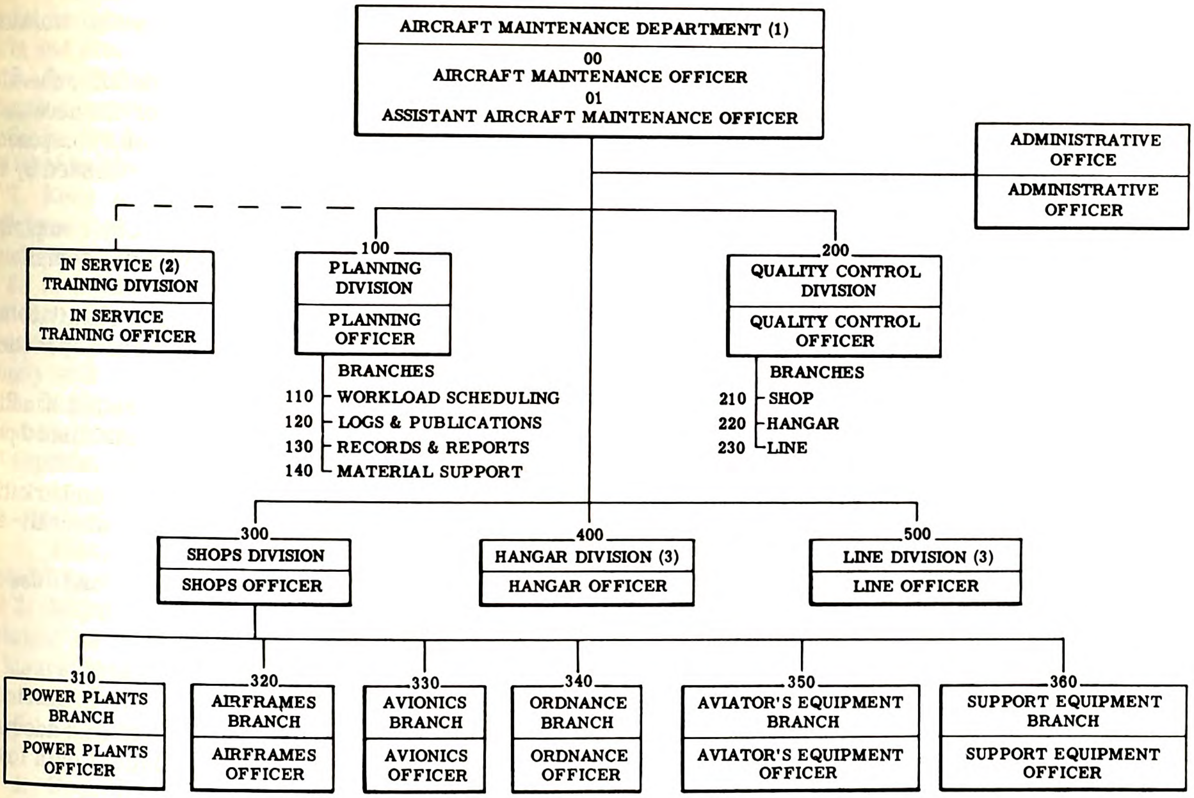
DEPARTMENT MANAGEMENT:

- 00 - Aircraft Maintenance Officer.
- 01 - Assistant Aircraft Maintenance Offic

SERVICE ACTIVITIES:

- 100 - Planning Division Officer
  - 110 - Workload Scheduling Branch.
  - 120 - Logs and Publications Bran
  - 130 - Records and Reports Bran
  - 140 - Material Support Branch.
- 200 - Quality Control Division Officer
  - 210 - Shop Branch.
  - 220 - Hangar Branch.
  - 230 - Line Branch.

ORGANIZATION CHART FOR AIRCRAFT MAINTENANCE ACTIVITIES
PERFORMING CLASS "B" AND "C" MAINTENANCE
(STAFF, SHOP, HANGAR AND LINE ARRANGEMENT)



(1) MAY BE A DIVISION AT APPLICABLE ACTIVITIES
(2) RESERVE TRAINING COMMAND ONLY
(3) SEE FIGURE 1-2 FOR DETAILS OF HANGAR AND LINE DIVISIONS.

Figure 1-1.—Supporting activity aircraft maintenance organizational chart.

PRODUCTION ACTIVITIES:

- 300 - Shops Division Officer
  - 310 - Power Plants Branch.
  - 320 - Airframes Branch.
  - 330 - Avionics Branch.
  - 340 - Ordnance Branch.
  - 350 - Aviation Equipment Branch.
  - 360 - Support Equipment Branch.
- 400 - Hangar Division Officer
  - 410 - Power Plants Branch.
  - 420 - Airframes Branch.
  - 430 - Avionics Branch.
  - 440 - Ordnance Branch.
  - 450 - Aviation Equipment Branch.
- 500 - Line Division Officer
  - 510 - Plane Captains Branch.
  - 520 - Trouble Shooting Branch.

The chart (fig. 1-1) is divided into four main groups—management (00), planning (100), quality control (200), and production (300, 400, 500). Note that the designation DIVISION is no longer applied to the individual shops. Shops are now designated BRANCHES and are segments of a division. Each division is headed by a division officer, and each branch is headed by a branch officer.

MANAGEMENT

The aircraft maintenance officer is the head of the aircraft maintenance department and is responsible to the commanding officer for the accomplishment of the department's mission.

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PLANNING

The function of the planning division is:

100 - Planning Division:

1. Keep the aircraft maintenance officer and assistant aircraft maintenance officer advised of the status of all present and future maintenance programs affecting the department. Recommend improvements or changes in policy where deemed necessary or desirable which affect operations, safety of flight, greater economy, improved efficiency or better implementation of the productive effort of the department.
2. Screen directives received from BuWeps, fleet, force and type commanders and the aircraft maintenance officer for applicability. Forward copies of applicable directives to the appropriate divisions.
3. Plan workload and schedule maintenance work.
4. Prepare and distribute smooth copies of approved maintenance instructions.
5. Provide requisition control number information on the maintenance instruction.
6. Initiate requests for material.
7. Initiate work orders on scheduled work.
8. Maintain the status board.
9. Prepare work requests to and maintain liaison with the supporting activity.
10. Process FURS and EFR reports.
11. Recommend to the aircraft maintenance officer corrective action for the improvement in maintenance policies, procedures and training.
12. Establish a continuing control and coordination of actions of the division to insure prompt movement of aircraft and engines, parts, materials and manpower. Establish the proper transportation and communication systems to provide complete support of the workload.

110 - Workload Scheduling Branch:

1. Plan workload and schedule maintenance work.
2. Initiate work orders on scheduled work.
3. Insure that workload commitments are compatible with productive capacity.
4. Continually review and evaluate the productive capabilities and operations in order to meet changing conditions effectively.
5. Maintain cognizance and coordination of the workload scheduling activity in the department.
6. Correlate the departmental workload with productive capacity.
7. Prepare program and detail schedules and direct manhour estimates for the necessary maintenance of aircraft, engines, components and support equipments to be processed by the department.
8. Assign jobs, priorities, completion times, and check progress to insure compliance with the established schedules.
9. Plan the movement of aircraft to and from parking area and working area as practicable.
10. Plan the movement of ground handling equipment in accordance with established priorities and procedures.
11. Assist those concerned with embarkation and de-embarkation loading of aircraft and equipment as required.
12. Monitor the availability and use of maintenance personnel.

120 - Logs and Publications Branch:

1. Insure prompt acquisition and adequate dissemination of pertinent technical data to the lowest level required to know.
2. Maintain a technical publications and correspondence library.
3. Secure applicable classified data.
4. Maintain logs, such as aircraft, engine, and others as may be required, in accordance with BuWeps Instructions.
5. Insure the correct disposition of all logs and publications.

6. Make proper distribution of all technical information and publications.

7. Insure that aircraft inventories are complete, that logbook entries are made, authenticated and correct in all respects.

130 - Records and Reports Branch:

1. Establish and control a central reporti and record keeping system for all maintenanc reports and correspondence.
2. Maintain all correspondence and repor files for the aircraft maintenance departme except for those special reference files mai tained by each division or branch.

3. Make proper distribution of all nontechnical information and publications.

4. Publish and distribute approved locally issued maintenance directives, procedures, reports and studies.

5. Reproduce and distribute, as necessary, incoming messages and other data.

6. Insure that proper records in proper form are kept by the various divisions and branches.

7. Keep a master log of completed work order and maintenance instructions and maintain a current maintenance index record.

8. Maintain record control of work completions and compliance with maintenance instructions and maintain necessary records to comply with existing directives.

9. Implement all directives concerning distribution, retention and disposition of records and reports.

140 - Material Support Branch:

1. Plan, requisition and expedite material needed to support the workload.

2. Maintain liaision with the supply department on maintenance material matters and to insure that material needs of the aircraft maintenance department are satisfied.

3. Compile and analyze maintenance usage data.

4. Coordinate action with the quality control division for the determination of quality, condition and quantity of material and spare parts received RFI.

5. Furnish technical advice and information to the supply department as to the identity and quantity of supplies, spare parts, and materials necessary to accomplish the assigned workload.

6. Establish standard operating procedures which will insure the inventory of tools and the adequate accountability of pre-issue items (special tools and equipment).

7. Initiate work requests on material and/or equipment requiring repair.

8. Initiate surveys in the event of loss, damage, or destruction of accountable items of material and/or equipment.

9. Keep the aircraft maintenance officer advised of the overall supply situation as it affects the aircraft maintenance department.

10. Verify AOCP (aircraft out of commission for parts) and ANFE (aircraft not fully equipped) requisitions and maintain, by aircraft serial number, current AOCP and ANFE status.

11. Recommend and control cannibalization in accordance with applicable directives when such action is deemed advisable in the best interest of the operations.

12. Observe and report on qualitative results of preservation and packaging of material received.

QUALITY CONTROL

Quality control includes many different functions. Not the least of these is the responsibility for the quality of workmanship within the maintenance department. The functions of the quality control division are as follows:

1. Establish inspection procedures and standards to insure that maintenance and repair work on aircraft, engines, accessories and equipage has been performed in accordance with current Navy standards and safety of flight requirements.

2. Act as a full-time quality control representative of the aircraft maintenance officer to maintain a high level of quality and safety of products produced.

3. Insure the inspection of aircraft coming under the cognizance of the aircraft maintenance department for shop, hangar or line maintenance, to determine that the aircraft are, upon completion of such work, ready for flight in all respects. This inspection includes not only the inspection of actual work performed but also the checking for operability of elements of the aircraft which have been disconnected or torn down in order to perform such work.

4. Insure the inspection of RFI material and spares for acceptable quality and necessary modifications.

5. Maintain a current list of all personnel authorized by their supervisors to perform inspection duties and hold their branch supervisors responsible for an understanding of inspection procedures prescribed by the quality control division.

6. Provide for inspection coverage at all times regardless of what phase of maintenance is being performed.

7. Interpret applicable directives and prepare maintenance instructions necessary to implement such directives.

8. Provide supplementary forms for such inspection control as may be necessary.

9. Supervise a weekly pilots aircraft inspection program on assigned aircraft.

10. Maintain adequate technical information to support inspection operations.

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11. Determine that maintenance flight tests on aircraft have been performed as required.

12. Determine that sufficient ground checks and preflight inspections have been performed on aircraft processed by the department for acceptable quality and safety of flight requirements.

13. Review discrepancies found by pilots during flight for the purpose of improving quality of inspection procedures.

14. Obtain information from operating squadrons and activities performing higher echelons of maintenance work to determine ways and means of improving quality of workmanship in the Aircraft Maintenance Department.

15. Insure adequate training of personnel in quality control procedures in order to qualify designated personnel as inspectors.

16. Analyze discrepancy and quality trends on aircraft assigned to the department for maintenance and provide followup action and functional guidance to stimulate improvement of quality on a departmental basis.

210 - Shops Quality Control Branch:

Provide inspection services for the class C and D maintenance task. Conduct inspections and insure quality of products resulting from: bench check, tests, calibration, modification and repair of accessories and components; repair of aircraft; manufacture of certain parts; machine work; accomplishment of specified changes and bulletins; replacement of minor parts; and in certain cases, magnetic particle and dye penetrant inspection, and perform additional inspections as directed by the shops division and/or higher authority. These inspection services are provided by quality control division personnel or designated inspectors of the various branches of the shops division.

220 - Hangar Quality Control Branch:

Provide inspection services for the class E maintenance task. Conduct inspection and report on quality of product resulting from work completed by the various branches of the hangar division. Conduct all inspections of routine work, engine changes, periodic and special checks, replacement of components and accessories, incorporation of specified changes and bulletins, and perform additional inspections as directed by the hangar division and/or higher authority. These inspection services are provided by quality control division personnel or designated inspectors of the various branches of the hangar division.

230 - Line Quality Control Branch:

Provide inspection services for the class F maintenance task. Conduct inspection and insure high quality of product through daily and preflight inspections, adjustments, servicing, correction of minor discrepancies and troubleshooting. Perform additional inspections as directed by the line division and/or higher authority. These inspection services are provided by quality control division personnel or designated inspectors of the line division.

The AT should always bear in mind that quality control is not merely an inspection process. The role of inspection is to measure the qualitative results of the production activity against design standards. Quality cannot be inspected into a piece of work. It must be built into it. The control of quality should begin with the Commanding Officer and extend throughout the organization. Quality is everybody's business.

PRODUCTION

This is the division that includes the shop, hangar, and line branches. Its functions are:

300 - Shops Division:

Be responsible for the accomplishment of Class C and D maintenance tasks on assigned and supported aircraft components, aviation equipment, and aircraft ground support equipment. Be responsible for assisting hangar and line division personnel in Class E and F maintenance tasks when directed by the aircraft maintenance officer. Be responsible for the performance of the following administrative functions:

1. Initiate work requests for unscheduled work as necessary.

2. Interpret applicable directives and prepare in rough draft form maintenance instructions to implement such directives.

3. Designate qualified individuals to perform required inspections and advise quality control division of such designees.

4. Initiate requests for material for aircraft and support equipment and maintain proper and sufficient stock levels to assure accomplishment of the workload and operational readiness.

5. Determine that all safety instructions issued by higher authority have been posted and complied with.

6. Prepare such additional safety instructions as required.

7. Support preventive maintenance programs as required.

8. Expedite shop work by continuous evaluation of shop methods and procedures and incorporate new techniques or changes as appropriate.

9. Insure the security of aircraft and aircraft equipment, the adequacy of tools and other support equipment, and the cleanliness of working areas used by the division.

10. Conduct on-the-job training of personnel.

11. Assume custody and accountability of assigned shop spaces, tools and equipment and assure their proper use.

330 - Avionics Branch:

Perform Class C and D maintenance tasks on aircraft avionics equipments and systems. Assist in Class E and F maintenance when directed by the aircraft maintenance officer. Perform administrative functions.

Perform technical functions within the scope of the following ratings: Aviation Electronics Technicians—(AT), (ATR), (ATS), (ATN), (ATW), and strikers; Aviation Electricians Mates—(AE), and strikers; Aviation Fire Control Technicians—(AQ), (AQF), (AQB) and strikers.

Squadron Organization

Figure 1-2 is the organizational chart for squadrons. Note that the shop and hangar divisions have been combined under the 400 code. The chart is divided into management (00), planning (100), quality control (200), material (600), and production (400 and 500). Each of the divisions in a squadron has the same mission as its comparable division in the supporting activity, as explained in connection with figure 1-1.

Forms and Procedures

Basic forms and procedures are set forth as guideposts to, and tools for, standard practices. Forms include a maintenance instruction (Form NavAer-5230), a work request (Form NavAer 5230A), and a work order and work accomplishment record (Form NavAer-5230B). Detailed instructions for preparation are printed on the back of each form.

Supplies of these forms may be requested on Aeronautic Publications and Forms Order Blank, NavAer-140, from the appropriate supply point listed on the reverse thereof and in accordance with instructions contained in the *Naval Aeronautic Publications Index,* NavWeps-00-500.

MAINTENANCE INSTRUCTION, Form NAVAER-5230.

This form is used at the squadron level for the interpretation and issuance of orders for compliance with directives received from higher authority or to implement local instructions. It is prepared by a division officer designated by the aircraft maintenance officer and is reviewed by the aircraft maintenance officer.

There are two general classes of work for which the maintenance instruction is used:

1. Single Action Maintenance Instruction (SAMI) is prepared for work of a one-time nature. When the work ordered is such that it will be completed on one aircraft or piece of equipment by carrying out the instructions set forth, and will not require further action at any time or in any situation on that aircraft or piece of equipment, it is properly the subject of a SAMI; for example, an aircraft service change on all bureau numbers of a certain model of aircraft.

2. A Continuing Action Maintenance Instruction (CAMI) is prepared when the work ordered is such that it may recur at intervals on the same aircraft or piece of equipment due to elapsed time or as a result of some situation, and is properly the subject of a CAMI; for example, an inspection of landing gear required whenever a hard or unusual landing has been reported.

A separate numbering system is set up for each type of maintenance instruction (SAMI or CAMI) for file control purposes and for

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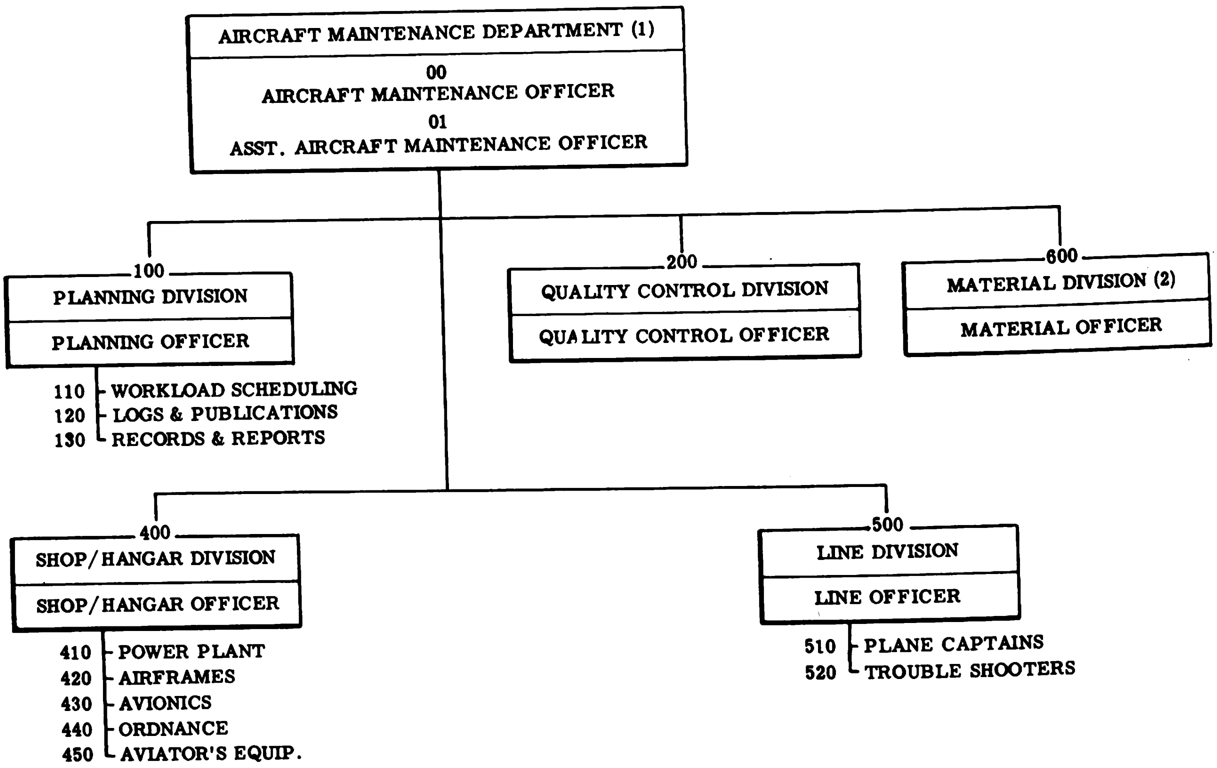

ORGANIZATION CHART FOR AIRCRAFT MAINTENANCE ACTIVITIES
PERFORMING CLASS "D", "E" AND "F" MAINTENANCE
(STAFF, SHOP/HANGAR AND LINE ARRANGEMENT)

(1) MAY BE A DIVISION AT APPLICABLE ACTIVITIES

(2) DELETE WHEN 3100 (SUPPLY) OFFICER IS AUTHORIZED BY NAVPERS 576, AND ESTABLISH 140 MATERIAL SUPPORT BRANCH IN PLANNING DIVISION IN ACCORDANCE WITH FIGURE 1-1.

Figure 1-2.—Squadron maintenance organizational chart.

cross reference on work orders. Each supporting work order will merely carry the serial number of the maintenance instruction rather than a repetition of an oftentimes lengthy work description.

WORK REQUEST Form NAVAER 5230A

This form is used by a supported activity to request that specific work be performed for it by its supporting activity. The work request originates in the support squadron for work that is beyond its own capacity to accomplish. The supporting activity reviews the request and approves or disapproves. If the request is approved, a work order number is assigned and the requesting activity is notified when the work is completed. If the request is disapproved, the reason therefor is entered on the Work Request and is returned to the originator.

WORK ORDER AND WORK ACCOMPLISHMENT RECORD, Form NAVAER-5230B.

This form is used to direct the performance of work and to carry out related supporting functions within the fleet maintenance activity, and to report its accomplishment. It is originated by the planning division (Code 100) or any of the other divisions, when necessary, and is used for routine work to correct discrepancies or for work necessary to comply with maintenance instructions. In the case of origination by other divisions the order is routed through Code 100 for scheduling purposes.

AIRCRAFT STATUS BOARD

This board is maintained to provide a visual presentation of current status information on all aircraft in the squadron. The aircraft status board (fig. 1-3) is of suitable size and material to display such information so that personnel having a need to know can quickly learn the essential facts. Size and location of the board will vary with each squadron employment and operating conditions.

MODEL	SQUAD NO.	BUREAU NO.	UP OR DOWN	ENGINE HOURS	HOURS TO INSP.	TYPE INSP.	MONTHS IN SERVICE	DATE LAST INSP.	REMARKS
F8U-1	101	12345	U	44.4	15.6	2nd INT	17	12·1·58	INSTALL ASC 208 NEXT INSP.
F8U-1	102	12356	D	55.5	23.8	ACCEPT	18	11·30·58	

Figure 1-3.—Aircraft status board.

WORK STATUS REPORT

The work status report is a periodic report prepared daily or weekly by the shop or division chief indicating the man-hours utilized on each work order scheduled in his particular shop or division. The report is prepared in duplicate, one copy for use in the shop to aid in work assignment control and one copy for the planning division (Code 100) to permit early adjustment of schedules. No format is prescribed in view of the variations in local operating conditions, practices and size of organization.

DUTIES OF THE LEADING PETTY OFFICER

Shop Administration

Some of the most important duties that you will be required to perform as a First Class or Chief Aviation Electronics Technician will be in connection with shop administration. As a shop supervisor you will be responsible for the work that is performed in the electronics shop as well as that performed on the line.

There are various aspects of shop administration. Some of the most important of these are discussed.

JOB PRIORITY, SCHEDULING, AND ASSIGNMENTS

Determining which jobs should be performed first will be one of your major responsibilities. This is an important phase of your work for these decisions determine the use of your facilities—men, material, and machinery. Routine work presents no particular problem to a well organized shop. Rush jobs can cause much confusion unless you have already thought them through and taken steps to see that the work follows well founded principles.

When scheduling work take steps to insure that you will have your men or crews working on different type jobs. If a number of men or crews are assigned to the same type jobs there will be an overdemand for certain test equipment, tools, and work space. This results in confusion and waste of time.

You should include known future assignments in your work schedule. If you know that at a certain date you must perform certain jobs you can rearrange your present work schedule so that routine work will have already been accomplished.

One of the most important aids in supervision is a job plan. When setting up a job plan, consider these questions: (1) What is the job? (2) how can it be accomplished? (3) how many men are required? (4) what tools and materials are necessary? Schedule activities so that work is accomplished in the proper sequence. This is especially important if you have men working on different phases of the same job.

In distributing work, be fair to all the men. It is a natural inclination, and a part of every person's makeup, to give the breaks to the people he likes. The important thing is to realize that you have this inclination and to control it. Avoid having a man do all the work of one type just because he happens to be an expert in that particular phase of the work. Pass the work around so that each man will get a chance to develop his skill in all phases of a technican's work. Assign your strikers to assist with various kinds of work so they will get experience on all kinds of jobs.

Rotating assignments makes the work more interesting for the men and, in addition, better qualifies them for advancement in rating. Another good reason for rotating assignments is that if one highly skilled man does all the work of a certain type, you and your shop will be at a great disadvantage should he ever leave the crew. Finally, avoid favoritism; it leads to poor morale and low production. Let ability be the measure of your men. Never give your men reason to believe that the only way to get ahead is to become your

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pal. Practice the principles of leadership and supervision until they become second nature.

INSPECTION

The supervisor's function as an inspector is vital to the efficiency and safety of an electronic shop. Frequent and thorough inspections are necessary to attain this twofold objective. On the one hand, check for cleanliness, the proper use of tools and equipment, and strict compliance with all safety precautions; on the other, insist on quality work. By training your men to keep the shop clean and orderly, you are encouraging orderly thought and systematic work habits which will be directly reflected in high quality workmanship. Through inspection you insure that jobs are completed with the most efficient and economical use of equipment and materials, and that work is performed in a safe manner.

Training

The Navy rightly places great emphasis on effective and continuous rate training. As you advance in seniority, it becomes your legal, moral, and practical responsibility to carry out a training program which is the very best of which you are capable.

It is your legal responsibility because your qualifications for advancement in rating clearly demand that you be able to set up and execute an effective training program.

Less explicit, but just as real, are the moral considerations involved. First of all, you are getting paid to do a job. Second, you are in a position of trust because of your greater experience and technical knowledge. For instance, pilots will most readily accept and fly aircraft that you, the senior shop technician, have worked on. To insure that they have equal confidence in the work of your junior men, they must be convinced that these men can do specific jobs as well as you yourself can. The only way you can obtain such proficiency in your men is to train them thoroughly.

Most important of all, there are practical aspects to the need for an excellent training program. Your squadron's operational readiness depends largely on the ability of its maintenance department. In turn, an important part of the maintenance department's work is done by the Aviation Electronics Technician. Consequently, the quality and scope of your training program has a very real effect on your squadron's effectiveness, and thus on national security. Another practical, though more personal, aspect to consider is that your own job is made easier each time a junior man is taught to do a job without close supervision. Also, when your shop gains the reputation of a "can-do" team, it reflects well on your own prestige.

PLANNING A TRAINING PROGRAM

The very first phase in developing your training program should be to determine and fix its objectives. On the squadron level, these objectives should be:

1. Training of men on subjects of a general nature as specified by the *Qualifications for Advancement in Rating*. (These appear in this course as appendix number X.) This training is intended primarily to aid the men in rate advancement.

2. Training of men on specialized subjects; namely, the circuits and equipment used in the squadron aircraft. This training is intended primarily to improve their daily working proficiency, and thus is generally of more direct benefit to the squadron than rate-advancement training.

The second phase in developing your training program includes a considerable number o steps. The most important of these are:

1. Evaluate each man to be instructed, fo the purpose of determining the starting leve of the subject matter. For instance, if one o more of your men has never attended a service school, you must commence instruction at th level of fundamental electricity and electronics

2. List the subjects to be taught. The inclusion of a number of the items on this list will b dictated by the *Manual of Qualifications for A vancement in Rating*. These will be gener subjects, a very few of which are electr theory, Ohm's law, capacitive and inducti characteristics, and fundamental transform theory. The remainder of the list will be made of specialized items pertaining only to t particular squadron's aircraft.

3. Search out reference books or public tions which cover all the items of the foregoi list. You must thoroughly understand each it yourself. At this same time, the subjects sho be arranged in the most logical sequence teaching.

4. Prepare a lesson plan for each subject. When the lesson plans are completed, they will have to be approved by the maintenance officer, because he is officially responsible for the contents of such training programs.

5. Procure space for carrying out the lecture-type portion of your program. This will usually be in the electronics shop. However, if other space is available, you should check such features as possible seating arrangements, ventilation, lighting, and outside noise levels.

TRAINING MATERIALS

There will be a limited number of items of training materials used in a squadron-level training program. Obviously, it would not be practical to build visual aids such as mockups and models, as is done in service schools. Your list of materials for the students probably will include only note pads, pencils, and as many study texts as you can procure from various sources. Your own essential materials will include lesson plans, training records, a blackboard, and chalk. The required materials will depend mostly on your individual situation. For instance, if you are in a constantly-moving carrier air group unit, your blackboard should be portable, and should fit in a cruise box. For teaching a patrol squadron crew, the blackboard could be larger and permanently attached to a bulkhead.

TRAINING METHODS

Training methods cover a large field, which is a course of study in itself. A closer and more detailed study of this field is made in the *Manual for Navy Instructors*, NavPers 16103-B. Also, the *Military Requirements* training courses, NavPers 10054, 10056, and 10057 contain information on training.

Only the simplest methods of training are mentioned here, but these should be sufficient for informal squadron-level instruction. The first lessons in your training program should deal with electrical and electronics fundamentals. These serve to prepare the men for the subsequent teaching of specialized equipment. Fundamentals will be taught mostly by lecturing and using a blackboard to illustrate important points. You should keep in mind during this stage that you are teaching general principles and terms which will be used verbatim when you teach specific circuits later on. That is, you must cover such fundamentals as vacuum tube theory and magnetic amplifiers so thoroughly that no question as to their operating principles will arise when they are later encountered in equipment.

The teaching of fundamentals on the squadron level is more difficult than at service schools, because you probably will not have the means to make demonstrations, or to set up lab problems. Consequently, some parts of the fundamental lessons will have to be carried over into the equipment phases. For instance, it can be stated in the classroom that all of the power produced in a UHF transmitter is not radiated from the antenna. Later, to demonstrate this point, while actually checking a transmitter's operation in your squadron's aircraft, you can focus the students' attention on the fact that the reading on the standing wave ratio (SWR) meter indicates that some power is lost, as compared to the stated power output of the transmitter. Thus, the student makes a mental connection between the statement of a general theory, and a factual example of that theory at work. This method of training is very effective.

At its best, classroom instruction is limited in effect. Really useful and practical knowledge is gained by your students when they apply fundamental and theoretical teachings to actual equipment. When you have advanced to the point of commencing instruction on specialized squadron aircraft equipment, your training methods must be changed somewhat. These changes will involve breaking each lesson into four stages, when teaching equipment. These stages are:

1. Extensive circuit theory and unit function, referencing HMI.
2. Operation and observation of the equipment in action, done by the student at the aircraft, under your supervision.
3. Making calibration or adjustment, done only when such adjustments are actually needed, and under your supervision.
4. Signal tracing, trouble isolation, and parts replacement, done when actually needed, and under your supervision.

Each equipment lesson will deal with only one electrical circuit or set at a time, and as many of the foregoing four steps as possible will be carried out in turn. In most cases only steps 1 and 2 will be carried out as routine instruction. Then, when you receive a discrepancy report on a circuit which has been

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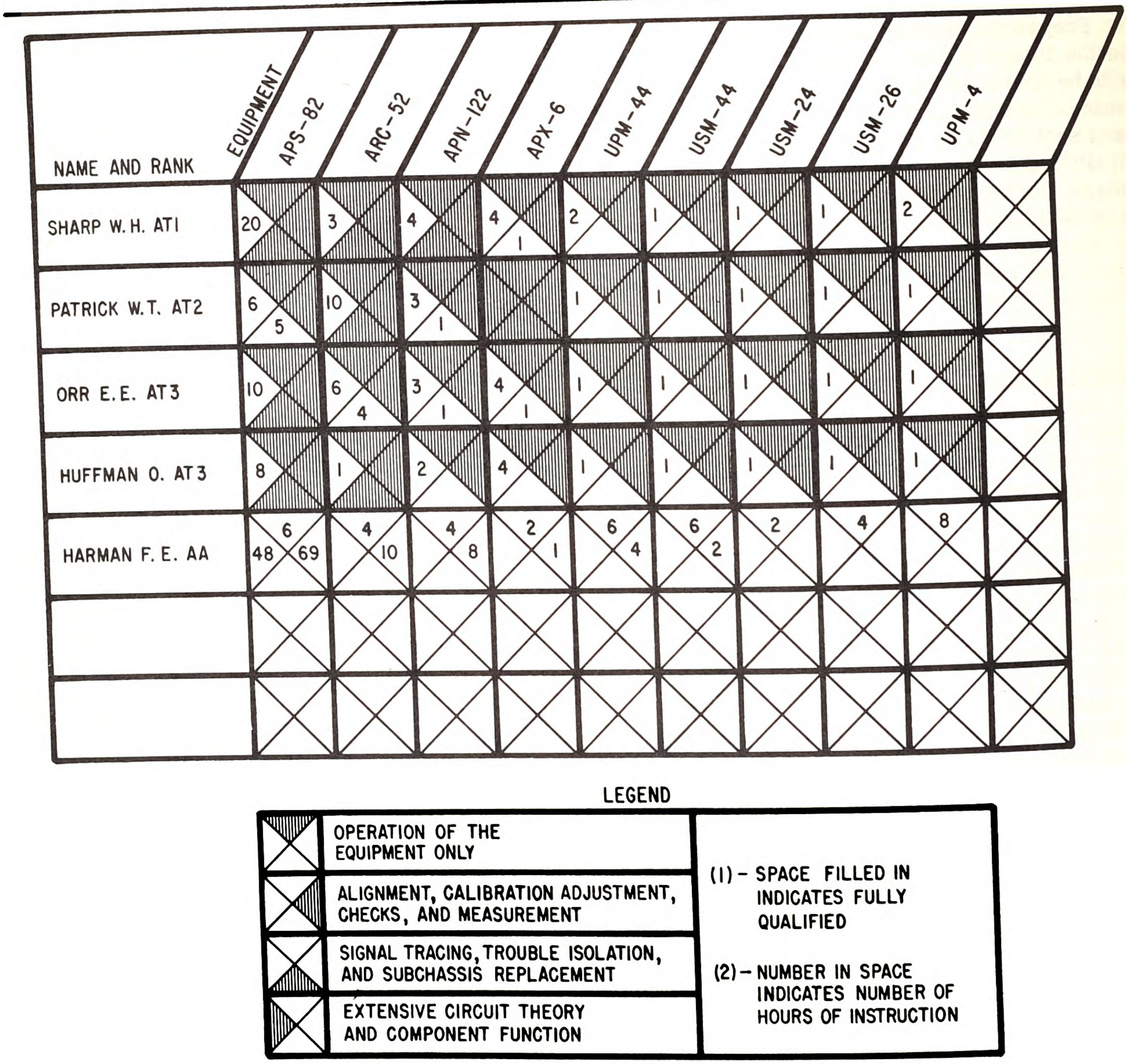

NAME AND RANK / EQUIPMENT	APS-82	ARC-52	APN-122	APX-6	UPM-44	USM-44	USM-24	USM-26	UPM-4	
SHARP W.H. AT1	20	3	4	4 1	2	1	1	1	2	
PATRICK W.T. AT2	6 5	10	3 1		1	1	1	1	1	
ORR E.E. AT3	10	6 4	3 1	4 1	1	1	1	1	1	
HUFFMAN O. AT3	8	1	2	4	1	1	1	1	1	
HARMAN F.E. AA	6 48 69	4 10	4 8	2 1	6 4	6 2	2	4	8	

LEGEND

- OPERATION OF THE EQUIPMENT ONLY
- ALIGNMENT, CALIBRATION ADJUSTMENT, CHECKS, AND MEASUREMENT
- SIGNAL TRACING, TROUBLE ISOLATION, AND SUBCHASSIS REPLACEMENT
- EXTENSIVE CIRCUIT THEORY AND COMPONENT FUNCTION

(1) - SPACE FILLED IN INDICATES FULLY QUALIFIED

(2) - NUMBER IN SPACE INDICATES NUMBER OF HOURS OF INSTRUCTION

Figure 1-4.—Training chart.

taught through steps 1 and 2, one or more of your students may accompany you to the aircraft and carry out steps 3 and 4. This method of training is thus seen to serve a dual purpose; it gets your men trained to do a job (the second time without your direct supervision), and also routine maintenance work is accomplished.

TRAINING RECORDS

From the foregoing, it is apparent that different men may become trained to different levels on different equipment. This is true because some may miss lessons at times. Th is also the probability of personnel turno Obviously, you must see that a training rec is carefully kept on each man, with an e made each time he has undergone any of the stages of instruction. A very good form to us shown in figure 1-4. By using this form, a m training level for any particular circuit o may be determined at a glance.

SCHEDULED TRAINING

It must be assumed from the start th inflexible training schedule will not work.

extreme variations in routine maintenance workload will not permit a fixed schedule. Therefore, training time must be taken whenever it is available. That is, it is scheduled only to the extent that it will be done if at all possible some time during the day, but the time will vary. When training is absolutely precluded by a heavy workload, it should be noted in the daily work log. Thus, the time can be made up when the workload is lighter.

NONSCHEDULED TRAINING

This consists merely of seizing unforeseen opportunities for purposes of training. For instance, an equipment mounting rack lying on a workbench may present the opportunity for you to launch into a discussion of it. This would be an ideal time for you to point out such features as the location of the power plug and explain why it is slightly movable, where and how safety wire should be attached, and how the rack is mounted in the aircraft. Remember, any information you are able to pass to your men, regardless of time, place, or subject matter, is actually a form of training. You should, however, keep careful track of what you have taught, and how thoroughly each subject has been covered.

QUIZ

1. The person who controls personnel assignment within divisions is the
   a. maintenance officer
   b. division officer
   c. commanding officer
   d. personnel officer

2. A good rule to remember is to censure privately and praise
   a. at no time
   b. to please a person
   c. in private
   d. in public

3. The division responsible for the processing of FURS is
   a. material
   b. quality control
   c. production
   d. planning

4. A book containing the "do's and don'ts" of leadership is
   a. Military Requirements 3 and 2
   b. Manual of Leadership
   c. Military Requirements 1 and C
   d. How to Lead Men, Volume II

5. Branches coded in the 100 series are
   a. line
   b. planning
   c. maintenance
   d. working

6. Military Requirements 3 and 2 are concerned primarily with knowledge that a petty officer must possess to
   a. pass his second class exams
   b. work independently and assume leadership duties
   c. stand shore patrol duty
   d. be a master at arms

7. Your attitude toward the chain of command is important because
   a. the men depend on your good attitude
   b. you cannot operate without the chain of command
   c. things could not get done otherwise
   d. the whole structure of the Navy depends on ascending and descending responsibilities

8. The upkeep of the aircraft status board is the responsibility of
   a. avionics
   b. logs and publications
   c. planning
   d. line

9. Hangar maintenance is classified as
   a. C
   b. D
   c. E
   d. F

10. The emergency manufacture of nonavailable parts is normally done by class ________ maintenance.
    a. A
    b. B
    c. C
    d. D

11. Voluntary discipline means that
    a. a person works because he wants to
    b. men work because they are told to
    c. the men work because they fear punishment
    d. the men discipline themselves when necessary

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12. The first phase in developing your training course should be to
    a. select a room
    b. obtain training aids
    c. train in basic things first
    d. determine and fix its objectives

13. A work status report is prepared
    a. daily or weekly by the shop chief
    b. monthly by the shop chief
    c. daily or weekly by the planning division
    d. monthly by the planning division

14. A SAMI is known as a
    a. single action maintenance instruction
    b. standing work order
    c. work order
    d. service change metal installation

15. Forms may be requested on Aeronauti Publications and Forms order blank
    a. NavAer-140
    b. NavAer--5230
    c. NavAer-5230A
    d. NavAer-00-500

CHAPTER 2

SUPPLY AND PUBLICATIONS

Aviation Supply

YOUR JOB IN SUPPLY

It is important that all naval personnel have a general knowledge of the principles of our present supply system in order to fully and correctly utilize the system. It is of primary importance that administrative and supervisory personnel have a working knowledge of the methods used to obtain and properly account for their particular supplies.

The first part of this chapter outlines your functions with regard to supply and tells you in a general way what you should know and be able to do in fulfilling this part of your job. As a first class or chief, you will probably be either fully or partially in charge of maintenance and operation in your division. You will, therefore, be instrumental in seeing that an adequate supply of authorized spare parts and other materials are available, and also you will help in planning for future needs. These, in general, are your main responsibilities with regard to supply.

FEDERAL CATALOGING SYSTEM

For many years, there were nearly as many ways of listing and classifying supplies as there were federal bureaus and services. The Army, Navy, and Air Force each had their own system of classifying, identifying, and cataloging supplies. In many instances, a given item would be listed in several different supply systems under different identifying numbers. Because of this situation, certain items of supply were often critically scarce in one system, while there might be a surplus of these items in another system. In such a case, the artificial shortage would cause the expense of buying new supplies for one system when they were already available in another. The personnel operating one supply system had no way of knowing what another system might have on hand. Obviously, inefficiency and unnecessary expense resulted from these methods of handling federal supplies.

Public Law 436 established authority for the Defense Department to develop a single federal cataloging system and a related program of supply standardization. The basic purpose of this program is to identify any item of supply carried in any government supply system with one distinctive name and number. In this way, in all services, bureaus, and departments the name and stock number of a given item of supply will be the same.

The law requires that all standardizing supply data be compiled into a single Federal Stock Catalog, consisting of a number of volumes, sections, and supplements. The Navy Stock List comprises a number of these volumes. Most of the parts and equipment that you will order will be listed in the ASO and ESO sections of the Navy Stock List. The ASO (Aviation Supply Office) section is explained later in this chapter. The ESO (Electronics Supply Office) sections list electronic parts used by all naval activities.

Activities will usually maintain sections of the Navy Stock List pertaining only to supplies related to their particular needs. For instance, a fighter squadron would maintain those sections pertaining to aviation equipment and parts, while a destroyer would maintain the ones pertaining to shipboard equipment. However, both the squadron and destroyer would probably maintain the section published by the Electronics Supply Office, because that section lists electronic parts which might be used by both activities.

For instance, a resistor of a certain resistance and wattage rating might be used in both a shipboard and an aircraft electronic circuit. Under the old supply system, identical

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resistors of this type would have been carried in two different supply systems under two different stock numbers and probably in two different catalogs. However, under the Federal Cataloging System, the standardized method of describing and classifying parts would cause both resistors to be assigned the same Federal Stock Number and be listed in the same catalog. This catalog would be a section or part of a section controlled by the Electronics Supply Office.

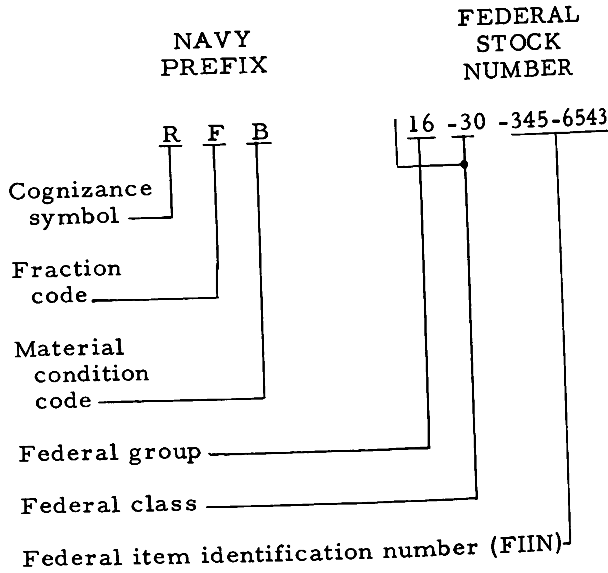
It is important to note that the law establishing the Federal Cataloging System directed that items of supply be listed by their description as well as their application. For this reason, you will find a description of every article listed in the Navy Stock List; this description will be as complete as practical. The following is taken from an Electronics Supply Office (ESO) section to show the description given a single resistor. The information given is the Federal Stock Number, section item number, resistance, tolerance (%), power rating in watts, maximum operating temperature, inductance if any, style of shape and mounting, dimensions, resistance to humidity, specifications met in manufacture, and additional information such as type of coating.

Some confusion may exist at this point as to who would have cognizance of (control over) any given piece of equipment or electronic part. If the entire piece of equipment (such as a direction finder) is specialized to aviation use, it would be listed in the ASO section. However, parts of this direction finder such as tubes, resistors, and capacitors would be listed in the ESO section because they will also be used by nonaviation activities.

FEDERAL STOCK CATALOG

This catalog will eventually be comprised of every item of equipment and supply that is continuously bought and used by any government bureau, service, or department. However, the only parts of this catalog you are likely to see will be the Navy Stock List. The conversion of Standard Navy Stock Numbers (SNSN's) to Federal Stock Numbers (FSN's) has been a long and complicated process. Nevertheless, the Federal Stock Catalog will eventually have a federal stock number, standard name and description, unit price, and application for all items of supply which once carried Standard Navy Stock Numbers. It will do the same for items used by other services and departments as well.

An example of a federal stock number with the Navy prefix is shown below.



The Navy prefix to the FSN is a three-lett code that designates the following:

1. The first letter indicates the cogniza office or bureau.
2. The second letter is the fraction coc and indicates usage or procurement.
3. The third letter indicates if the mater is new, salvage, or used, and the ext of renovation that may be necessary used equipment.

The federal stock number contains th groups of digits. The first two groups (16 30 the example, designate the federal supply cl to which the material belongs, and are cal FSC. The first of these groups (16 in example) indicates the federal supply class cation group to which the material is assign

Following the FSC (first four digits) is FIIN, or federal item identification numbe is a seven-digit group that is serially assig as items of material are identified.

Variations of the federal stock number used. An interim stock number, for insta is assigned by ASO, but is later replaced permanent FSN. Local stock numbers are signed by field activities to items locally ma factured or not carried as system stock ite Coded federal stock numbers are used to i cate the type of material and the manufactu

All of the variations listed above use the federal stock number as their basis.

The Navy Stock List will be a complete listing of Federal Stock Catalog items used by the Navy. The Navy Stock List is further broken down into sections under the control of various offices, such as the Aviation Supply Office and Electronics Supply Office. Each section will furnish detailed information about specific items of a general type of equipment. For instance, a whole section is devoted to rectifiers as a general type of equipment, and then further broken down into specific types of rectifiers. It is important that the AT be able to identify and select that section of the Navy Stock List which pertains to equipment he wishes to order from supply.

AVIATION SUPPLY OFFICE

The Aviation Supply Office (ASO) is a joint agency of the Bureau of Supplies and Accounts (BuSandA) and the Bureau of Naval Weapons (BuWeps). The ASO exercises inventory control over most of those items of the Navy Stock List which pertain to aviation. (These items are grouped in the Aviation Supply Office sections of the Navy Stock Lists.) The primary functions of the Aviation Supply Office are as follows:

1. Procurement of most aeronautical supplies from manufacturers or other government departments.
2. Disposal of surplus materials.
3. Distribution, control of storage, and inventory control of aeronautical materials after procurement.
4. Completion of statistical information to aid in future procurement and distribution of aeronautical materials.
5. Classification and cataloging of aeronautical materials, and the distribution of such materials.
6. General control and rationing of critical aeronautical materials with the exception of that material controlled directly by BuWeps and fleet commands.

Material Control

The distribution of all aviation material is under the control of some office or bureau of the Navy Department or Fleet Command. That material under the latter control is known as FLEET-CONTROLLED MATERIAL and includes those items that are critical due to shortages of supply. Designation of items as fleet-controlled material is made by ASO in the ASO Monthly Critical List on the basis of recommendations made by the Fleet Commands. Distribution and issuance of fleet-controlled material is made only upon the approval of representatives of the fleet.

The theory behind this system of rationing is that such scarce materials must be used where needed most, and the respective Fleet Commands, being well acquainted with their own operational requirements, are the people most aware of which activity will have the greatest need for each item of critical material.

Distribution of most electronic items of aeronautical material is under the control of the Bureau of Naval Weapons. The nature of the material determines the cognizant agency. Inventory control for the majority of material under the cognizance of BuWeps is delegated to ASO.

A partial listing of the control symbols and the cognizant control office or bureau that should be of interest to the Aviation Electronics Technician is as follows:

COGNIZANCE CONTROL SYMBOL	COGNIZANCE SUPPLY CONTROL OFFICE OR BUREAU
A	Ordnance Supply Office
N	Electronic Supply Office
R	Aviation Supply Office
V	Bureau of Naval Weapons
I	Forms and Publications Supply Office
Z	Ordnance Supply Office

Distribution

To facilitate distribution of aeronautical material, the Aviation Supply Office has established several supply activities. These are:

1. Reserve stock points.
2. Distribution stock points.
3. Primary stock points.
4. Secondary stock points.
5. Satellites.

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The function of each of the supply activities is as follows:

Reserve stock points are activities which carry reserve and backup stock for the supply system. These units maintain storehouse facilities for the bulk storage of aeronautical material.

Distribution stock points are activities carrying stock for the supply support of designated primary and secondary stock points.

Primary stock points are units carrying stock for their own consumption and for the supply support of designated activities as secondary stock points, fleet units, yards, district craft, and assigned aircraft. Primary stock points also furnish complete aeronautical supply support to activities designated as satellites.

Secondary stock points are units which carry stock for their own consumption and for the support of assigned aircraft. These activities are shore-based units, continental or extra-continental, which are not classified at a higher level.

Satellites are aeronautical activities which are dependent on a primary or a secondary stock point for complete aeronautical supply support. Such activities will usually be auxiliary air stations, air facilities, and other minor supply activities.

The relationship existing between the various units of the aviation supply system can be understood better by studying the flow chart of aeronautical material shown in figure 2-1.

ORDERING PARTS AND EQUIPMENT

The AT will use many different sections of the Navy Stock List to obtain ordering information for the parts and equipment needed in aircraft maintenance. The proper use of these sections and other publications pertaining to supply will enable you to obtain replacement parts and equipment with a minimum of time and trouble. Certain publications and records which are not a part of the Navy Stock List, but are useful as references, will also be of much use. These include shop records, the *Handbook of Maintenance Instruction* (HMI), the *Illustrated Parts Breakdown* (IPB), and the Section B allowance list.

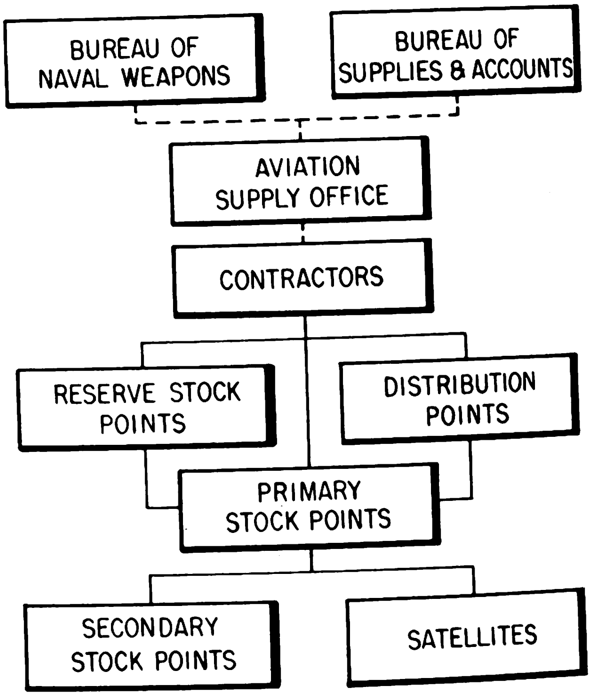

Figure 2-1.—Flow chart of aeronautical material.

Shop Material Records

An excellent rule to follow in ordering pa is to keep complete shop records. A logbo or card file record of material ordered sho be maintained for a number of reasons. One the best reasons is that these records, if pr erly kept, furnish an excellent source of formation when a particular part is orde more than once. The shop material rec should show the correct name of a part orde the stock number, quantity ordered, date orde intended use, and the date the part is recei In addition, there should be a clear descrip of where the ordering information was obtai This should include the catalog section num item number, and section page number. information should be recorded each time a is ordered. In this way, you will need to se for ordering information in the Navy Stock for a particular part only once. Upon reorde this part, you can simply copy this inform from the material record.

Section B Allowance List

This list is compiled and distribute BuWeps and is comprised of supply items have the greatest turnover for a certain type of aircraft. According to the number of planes a squadron might have, the Section B allowance list gives the quantity of certain types of parts a squadron might expect to use over a 90-day period. It also shows how many of a certain part or component are used on a single aircraft. From the standpoint of ordering parts, the Section B allowance list is most useful because it gives needed ordering information for all items listed. Its greatest limitation is that it lists relatively few of all the parts on an aircraft. You will become more familiar with its contents by using it. After repeated usage, you will often know without looking which items appear in the Section B allowance list and which ones do not.

The use of the *Handbook of Maintenance Instructions* and the *Illustrated Parts Breakdown* in obtaining stock numbers is covered in the following section of this chapter.

Cross Referencing of Federal Stock Numbers

Up to now, the discussion has dealt with ways of finding and using ordering information without using sections of the Navy Stock List. This method did not involve the cross-referencing of part numbers to Federal Stock Numbers. When the ordering information for a part is not listed in shop material records or in the Section B allowance lists, you must then be able to use the Navy Stock List. The locating of a federal stock number in the Navy Stock List involves certain clear-cut steps, each of which is done in a definite sequence. These steps are:

1. Determine manufacturer and manufacturer's part number of part to be ordered.
2. Determine equipment category or part (accessory, actuator, instrument, power plant accessory, and so forth.)
3. Select section of Navy Stock List pertaining to that category.
4. Use Navy Stock List section to cross-reference manufacturer's part number to Federal Stock Number.
5. Use Navy Stock List section further to determine complete description and applications of part.
6. Complete requisition form and submit to activity supply office.

Determining Part Numbers

The part number is a group of letters or numbers, or a combination of letters and numbers. This number is assigned to a part by the manufacturer, and appears on the part's nameplate. Small parts having no nameplate usually bear a stenciled part number. The manufacturer's part number for a given item may be obtained in several ways. The first and easiest way, of course, is to read it from the part's nameplate. However, this is not always possible. The part number may have been obliterated, or the part may be mounted at some inaccessible location where the number is not visible. The *Handbook of Maintenance Instructions* will often give the manufacturer's part number for major parts of electronic systems. In some HMI's, a list of part names with their respective part numbers will appear on the same page as the schematic diagram of a system. In other HMI's, these numbers and the manufacturer's name will be printed immediately beside the symbol for each part.

Another publication, the *Illustrated Parts Breakdown* (IPB), can be of more aid in obtaining part numbers. The IPB has highly detailed illustrations of each section of an airplane by systems. Figure 2-2 shows one of these illustrations found in the IPB for an S2F, fuselage section. Within the rough outline of the fuselage is shown some of the electronic system components in their correct locations. Note that each component or part has a reference number. In the IPB, these reference numbers will be listed and after each reference number will appear the component's correct part number and proper name. This name and part number will be used in cross-referencing the proper Navy Stock List section to obtain ordering information.

Accountability Symbols

The level of accountability for all material is not the same. This level is established by the accountability symbol assigned by the Bureau of Naval Weapons. All items received will be identified with a symbol that determines the type of accountability required. The symbol for a particular item may be obtained from allowance lists and also from the stock number data section of the Navy Stock List of the

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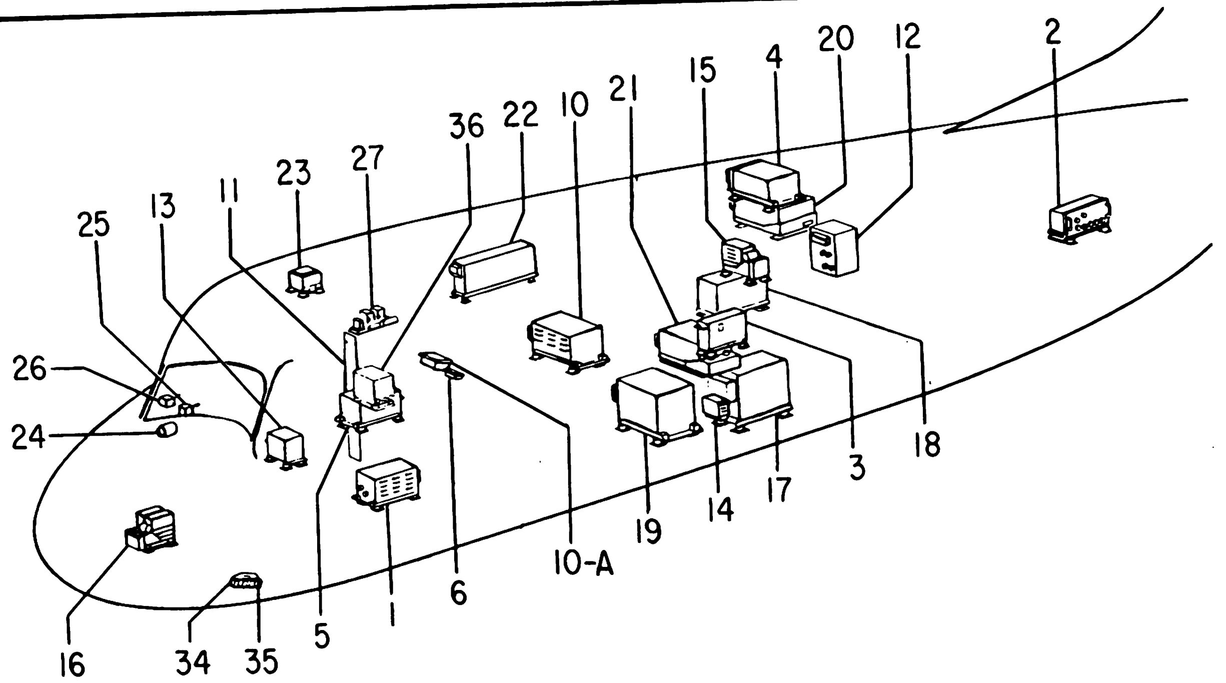

Figure 2-2.—Typical IPB parts illustration.

Aviation Supply Office. In allowance lists the symbol is placed in a column to the right of the listed item; the symbol is stamped on the nameplates of serialized components.

Accountability symbols are useful when—

1. Requisitioning material.
2. Accounting for material that is in use.
3. Disposing of material (turn-in).
4. Processing material for repair or overhaul.
5. Accounting for lost items.

Accountability symbols are as follows:

1. A—Plant property.
2. C—Consumable. These items are considered expendable or consumed in use, and are issued without a turn-in of the replaced item.
3. D—Disposal. These items are technical aviation material and are not issued for replacement purposes without a turn-in of the replaced item.
4. E—Equipage. These items are maintained on a custodial signature basis and will be surveyed when lost or missing.
5. O—Repairable plant property.
6. R—Repairable. These items are not issued for replacement without a turn-in of the replaced item. However, they may be drawn for initial installation without a turn-in.

Inventory Control

Inventory control may be defined as
formulation and administration of a system
policies and directives concerned with
determination of requirements or excesses
the action necessary to satisfy such requi
ments or dispose of such excesses. Examp
of activities that perform these functions, un
overall BuSandA direction, are the Avia
Supply Office (Philadelphia), and the Electro
Supply Office (Great Lakes).

Within the inventory control operation of
shore establishment, Ready-Issue Stores
Shop Stores are for the purpose of getting sp
parts and consumables as close to the use
possible and still keep the materials in
accounts of the Navy until they are re
needed.

The supporting units for aircraft squad
have the responsibility for establishing
operating the ready-issue stores under a Su
Corps officer of the shore activity. The r
and quantity of items carried is determin
the supply officer, guided by usage data,
plicable allowance lists, and recommenda
submitted by the units supported. A parti
effort is made to stock parts and materi
which there is the greatest demand, alth

quantities of items carried normally will not exceed requirements for 60 days.

Shop stores are operated in somewhat the same manner as ready-issue stores except that they are located primarily in industrial or repair activity shop areas, such as in an Overhaul and Repair Department of an air station. In this manner the stored stock is specialized, stock control and issue are simplified, and the store is operated by personnel who are connected with the shop concerned and familiar with its material requirements.

An inventory is the process of counting and recording the actual quantities of material on hand. Its primary purpose is to bring quantities shown on stock records into balance with actual quantities on hand.

You will be concerned primarily with inventorying aircraft electronic equipment, assemblies, subassemblies, parts, and associated equipment. Whether prescribed locally or by the controlling authority, inventories provide a basis for (1) requisitioning material, (2) accounting for use of material, and (3) disposition of excess material. Controlling activities normally supply inventory forms specifically designed for reporting categories of equipments for which they have cognizance.

Source Codes

Source codes are codes which indicate to a consumer a source for a part required in the maintenance or repair of an aeronautical article. Specifically, these codes indicate whether the material is to be requisitioned from the supply system; to be manufactured; to be obtained from salvage; not to be replaced since the next higher assembly is to be installed; not to be replaced due to the impracticability of replacement; to be procured for the specific requirement; to use local discretion regarding obtaining a replacement; or failure of the part indicates a requirement for complete overhaul or scrapping of the assembly or equipment.

When ordering a part of an electronic equipment, always check the source code since this may enable you to prevent much delay in procuring the item. For example, an item may be available only to an overhaul and repair activity and by knowing this you will not submit an incorrect requisition for that particular item. These codes are listed in the *Illustrated Parts Breakdowns* adjacent to the named part.

Source codes are assigned by BuWeps with the assistance and recommendations of the Fleet, ASO, O&R activities, and others. Anticipated or known usage is the primary factor in the assignment of source codes.

It should be noted that bulk materials, standard AN hardware, washers, nuts and bolts, and so forth are not assigned code numbers but are stocked and considered as items of normal inventory stock control.

Source codes that apply to most of the equipment and parts that the Aviation Electronics Technician is required to work with are as follows:

Source code P applies to items which are purchased in view of known or anticipated usage and which are relatively simple to manufacture within the Navy, if necessary.

Source code P1 applies to items which are purchased in view of known or anticipated usage and which are very difficult, impractical, or uneconomical to manufacture within the Navy.

Source code P2 applies to items for which little usage is anticipated but which are purchased in limited quantity for insurance purposes. Items coded P2 are difficult to manufacture, require special tooling and/or stock not normally available within the Naval Establishment, or require long production lead time.

Source code P3 applies to detail items which are purchased in quantity in accordance with the life expectancy of the part. Items coded P3 are deteriorative in nature and may require special storage conditions.

Source code P4 applies to end items which are procured for initial outfitting only, and which are placed by salvage, manufacture, or assembly at the lowest capable level of maintenance.

Source code M-F applies to items which are capable of being manufactured within Class C, D, E, or F activities. Items coded M-F have no anticipated or relatively low usage, nor do they possess restrictive installation or storage factors. With respect to support equipment, the manufacturing activity may alter the design, material, and/or processes provided that fit, function, use, and safety are not impaired.

Source code M-O applies to items which are capable of being manufactured within Class A or B activities. Items coded M-O have no anticipated or relatively low usage, or possess restrictive installation or storage factors.

Source code A-F applies to assemblies which are not purchased but which are to be

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assembled within Class C, D, E, or F activities prior to installation.

Source code A-O applies to assemblies which are not purchased but which are to be assembled within Class A or B activities prior to installation.

Source Code N applies to items which do not meet established criteria for stocking and which are normally readily available from commercial sources. These items are purchased on demand and are for immediate consumption and will not be stock numbered.

A working knowledge of the source coding program will enable you to more efficiently carry out your duties in effecting repair of equipment with a minimum of delay in waiting for replacement parts. Source coding of aeronautical articles insures a more effective control over manufacturing and procurement, establishes a universal means of obtaining material, and eliminates questions in the technician's mind as to the proper sources of supply. A description of the source codes is in the front of the *Illustrated Parts Breakdowns*. For detailed information on source codes refer to BuAer Instruction 4420.3.

SCREENING ELECTRONIC EQUIPMENT

As a first class or chief, it will be your responsibility to determine if an electronic assembly or part should be repaired or turned in to Supply for credit or disposition. By utilizing spare equipments, spare parts, tools, and test equipment provided or available, using or servicing activities should exert maximum effort to effect repairs to defective equipment within their own organization.

When it becomes necessary to return material, there are prescribed procedures to be followed. The procedures are somewhat involved and require a great deal of effort, but are set forth in the *Bureau of Supplies and Accounts Manual* to facilitate this phase of electronics maintenance. All material that is returned should be identified with a color-coded tag or label. These denote whether the equipment or part is RFI, requires screening, is rejected, is repairable, or is a salvage component. Local instructions will provide you with directions for labeling and tagging your equipment.

Electronic equipment in need of repair or overhaul is returned to Supply as prospective condition code E or B material. This identifies the material or equipment that requires screen ing and/or overhaul prior to being placed in Ready for Issue (RFI) condition.

Materials returned as excess equipmen that are in proper operating order, will b identified as RFI.

Whenever activities are unable to effe repairs to a unit, assembly, or part whi necessitates return to Supply for dispositi and the requisitioning of replacement becau of the lack of parts, tools, test equipment, inadequate facilities, a report to that effe shall be made to the Bureau of Naval Weapo for analysis and study. This report may submitted as a comment on the failure repo by official letter, or other means. The formation submitted will be used for purpos of planning, correcting deficiencies, and i proving field maintenance.

In the event a component or test feature specific item of test equipment is defective, the cognizant activity desires to utilize te porarily the other components of the unit, complete test equipment may be retained a requisition submitted to the cognizant su officer. The requisition shall bear a nota that the unit is being retained pending rec of a replacement. For more detailed informa about repair of test equipment refer to Bu Instruction 10550.5A.

MATERIAL RELIABILITY REPORTS

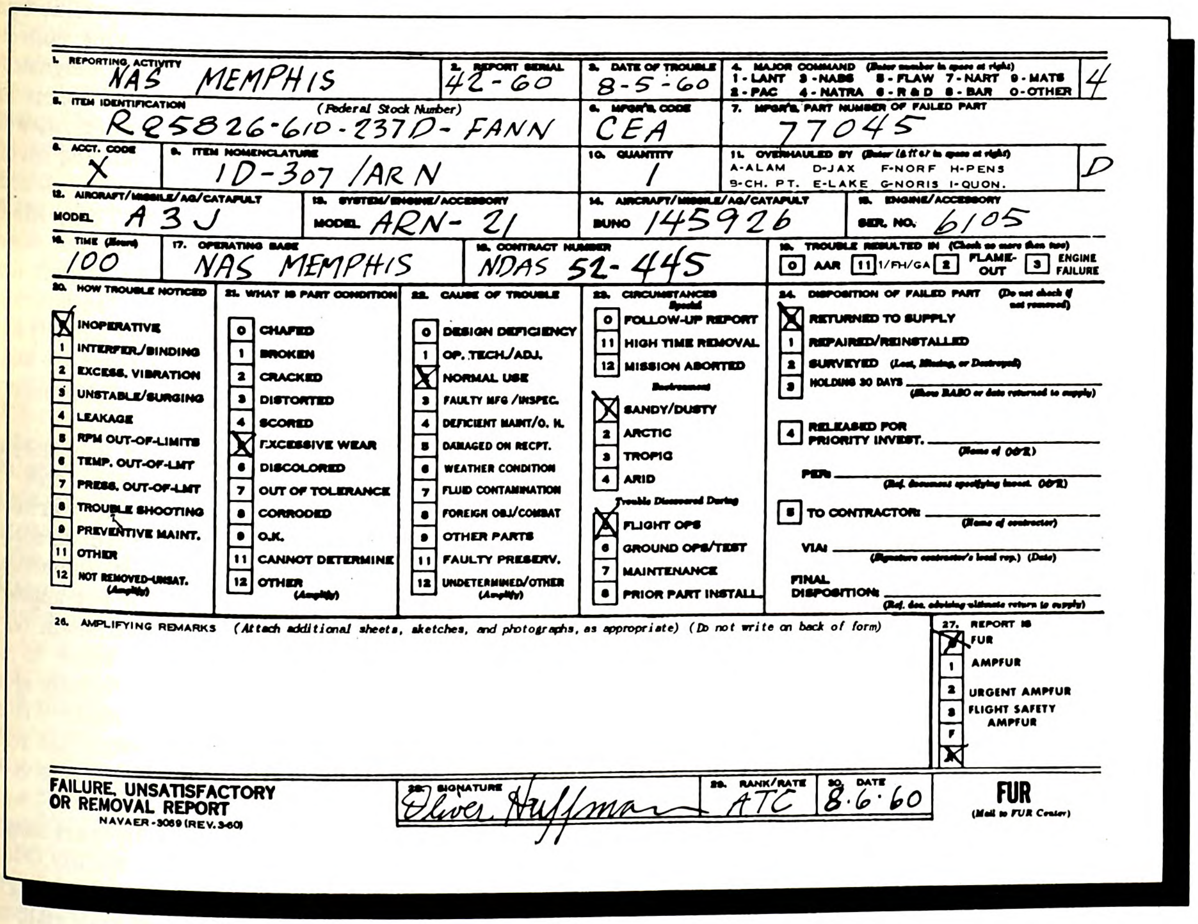
The purpose of the Naval Aeronautical terial Reliability Program is to enable Bureau of Naval Weapons and its contra to rapidly perform both statistical and tech analyses of equipment failures and to steps to insure that more reliable equipm developed. The major aspects of the pro are the collecting, compiling, and analyz service experience with naval aeronautica terials to determine areas of immediate fai and trends of impending failures, and t ordinate efforts to correct material defici to improve flight safety, operational utilit logistic support for operating aircraft.

The Material Reliability Program u two basic forms entitled Failure, Unsatisfa or Removal Report, (FUR) NavAer-3069 3-60), and Electronic Failure Report, DD787, for reporting all failures, fau malfunctions of aeronautical material. (The EFR is discussed in the training

AT 3 & 2, NavPers 10317-A.) Operating activities are responsible for the prompt submission of failure reports. As a first class or chief, you should insure that the reports submitted from your shop contain an accurate description of the failed item, including the correct stock number, part number, manufacturer, and contract number. Extraordinary efforts should be made to determine precise causes of component failures or malfunctions that are involved in aircraft accidents and FLIGA's (forced landings, incidents, ground accidents). If the determination of the causes of failures or malfunctions in these categories is beyond the capabilities of the reporting custodian and local supporting activities, priority disassembly and inspection reports or laboratory analysis reports, as appropriate, should be requested.

Failure, Unsatisfactory, or Removal Report (FUR)

Figure 2-3 illustrates a completed FUR. This is the latest revision of the FUR form as of the date of this writing. It must be remembered, however, that the material reliability forms (EFR and FUR) are revised periodically to meet the changing needs of the service. For that reason, it is impracticable to include here detailed instructions as to how each entry on the form should be completed. When the form is revised, the BuAer/BuWeps revision notice is usually accompanied by sufficiently detailed instructions for proper filling-in of the form. For the latest information relating to these forms refer to the current BuAer/BuWeps instruction.



1. REPORTING ACTIVITY NAS MEMPHIS

2. REPORT SERIAL 42-60

3. DATE OF TROUBLE 8-5-60

4. MAJOR COMMAND (Enter number in space at right) 1-LANT 3-NABS 5-FLAW 7-NART 9-MATS 2-PAC 4-NATRA 6-R&D 8-BAR 0-OTHER 4

5. ITEM IDENTIFICATION (Federal Stock Number) RQ5826-610-237D-FANN

6. MFGR'S CODE CEA

7. MFGR'S PART NUMBER OF FAILED PART 77045

8. ACCT. CODE X

9. ITEM NOMENCLATURE ID-307 /ARN

10. QUANTITY 1

11. OVERHAULED BY (Enter letter in space at right) A-ALAM D-JAX F-NORF H-PENS 9-CH. PT. E-LAKE G-NORIS I-QUON. D

12. AIRCRAFT/MISSILE/AG/CATAPULT MODEL A3J

13. SYSTEM/ENGINE/ACCESSORY MODEL ARN-21

14. AIRCRAFT/MISSILE/AG/CATAPULT BUNO 145926

15. ENGINE/ACCESSORY SER. NO. 6105

16. TIME (Hours) 100

17. OPERATING BASE NAS MEMPHIS

18. CONTRACT NUMBER NDAS 52-445

19. TROUBLE RESULTED IN (Check no more than two) 0 AAR 11 1/FH/GA 2 FLAME-OUT 3 ENGINE FAILURE

20. HOW TROUBLE NOTICED
- ☒ INOPERATIVE
- 1 INTERFER/BINDING
- 2 EXCESS. VIBRATION
- 3 UNSTABLE/SURGING
- 4 LEAKAGE
- 5 RPM OUT-OF-LIMITS
- 6 TEMP. OUT-OF-LMT
- 7 PRESS. OUT-OF-LMT
- 8 TROUBLE SHOOTING
- 9 PREVENTIVE MAINT.
- 11 OTHER
- 12 NOT REMOVED-UNSAT. (Amplify)

21. WHAT IS PART CONDITION
- 0 CHAFED
- 1 BROKEN
- 2 CRACKED
- 3 DISTORTED
- 4 SCORED
- ☒ EXCESSIVE WEAR
- 6 DISCOLORED
- 7 OUT OF TOLERANCE
- 8 CORRODED
- 9 O.K.
- 11 CANNOT DETERMINE
- 12 OTHER (Amplify)

22. CAUSE OF TROUBLE
- 0 DESIGN DEFICIENCY
- 1 OP. TECH/ADJ.
- ☒ NORMAL USE
- 3 FAULTY MFG /INSPEC.
- 4 DEFICIENT MAINT/O. H.
- 5 DAMAGED ON RECPT.
- 6 WEATHER CONDITION
- 7 FLUID CONTAMINATION
- 8 FOREIGN OBJ/COMBAT
- 9 OTHER PARTS
- 11 FAULTY PRESERV.
- 12 UNDETERMINED/OTHER (Amplify)

23. CIRCUMSTANCES

Special
- 0 FOLLOW-UP REPORT
- 11 HIGH TIME REMOVAL
- 12 MISSION ABORTED

Environment
- ☒ SANDY/DUSTY
- 2 ARCTIC
- 3 TROPIC
- 4 ARID

Trouble Discovered During
- ☒ FLIGHT OPS
- 6 GROUND OPS/TEST
- 7 MAINTENANCE
- 8 PRIOR PART INSTALL.

24. DISPOSITION OF FAILED PART (Do not check if not removed)
- ☒ RETURNED TO SUPPLY
- 1 REPAIRED/REINSTALLED
- 2 SURVEYED (Lost, Missing, or Destroyed)
- 3 HOLDING 30 DAYS ______ (Show BASO or date returned to supply)
- 4 RELEASED FOR PRIORITY INVEST. ______ (Name of O&R)

PER: ______ (Ref. document specifying invest. O&R)
- 5 TO CONTRACTOR: ______ (Name of contractor)

VIA: ______ (Signature contractor's local rep.) (Date)

FINAL DISPOSITION: ______ (Ref. doc. advising ultimate return to supply)

26. AMPLIFYING REMARKS (Attach additional sheets, sketches, and photographs, as appropriate) (Do not write on back of form)

27. REPORT IS
- ☒ FUR
- 1 AMPFUR
- 2 URGENT AMPFUR
- 3 FLIGHT SAFETY AMPFUR
- F
- ☒

FAILURE, UNSATISFACTORY OR REMOVAL REPORT
NAVAER-3069 (REV. 3-60)

28. SIGNATURE Oliver Huffman

29. RANK/RATE ATC

30. DATE 8·6·60

FUR (Mail to FUR Center)

Figure 2-3.—FUR (NavAer 3069, Rev. 3-60).

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FUR's are used throughout naval aviation to report failure or malfunction of parts, units, subassemblies, assemblies, sets, equipments, systems, and conditions. They serve to maintain a continuous system of reporting material and condition status of operating units and equipments so that weak spots may be eliminated and progressive improvement result. All maintenance and operating activities and units use the FUR, and it is mandatory that these forms be properly completed.

A FUR may be any one of four types, depending on what failure or unsatisfactory condition is being reported. A routine FUR bears no amplifying remarks; the checking of appropriate squares in each numbered space gives sufficient information. An AMPFUR, however, bears amplifying remarks. Whenever the remarks space contains an amplifying statement, the report is an AMPFUR.

URGENT and SAFETY OF FLIGHT FUR's are high-priority reports. The following criteria are suggested for priority report submission:

1. URGENT AMPFUR
   a. Flight safety is not involved.
   b. Aircraft availability is seriously impaired for assigned mission as a result of a particular material deficiency.
   c. Major material deficiencies are experienced on newly assigned aircraft, or on new production aircraft.
   d. No indication or corrective action being taken on previously reported failures or malfunctions in which excessive maintenance time is required. Activities should insure such problems have not been reviewed in the Reliability Digest prior to report submission.
   e. Unusual occurrences of material failures for which the cause cannot be determined.
2. FLIGHT SAFETY AMPFUR
   a. Failure or malfunction is the primary cause of an aircraft accident, forced landing, or incident.
   b. The primary cause of an accident or incident is undetermined, but a material deficiency was involved.
   c. Any other occurrence involving material deficiencies which in the opinion of the commanding officer involves flight safety.

MAINTENANCE USAGE DATA

Maintenance usage data give percentages of replacement relative to hours of aircraft and equipment operation. These percentages of replacement are applied to operational plans to determine probable future usage. Usage data are used in connection with the PURS (Program Usage Replenishment System) Program and as such are an important part of that program because it furnishes data from the field and fleet. Usage data determine the quantities of materials that will be placed on allowance lists. With that in mind, you can easily see the importance o the information that they contain. The lack o accurate and timely usage information can caus material shortages. Only a well-organized an smoothly functioning usage data program ca show realistic material needs, and reduce to minimum the element of guess work in th determination of material requirements.

Maintenance Usage Data Report forms ar provided for the use of activities reportin usage data. The cover page form indicates th model aircraft or the type of the avionic equipment for which usage data is being collecte Operating maintenance activities designated the cognizant command use these forms as usage report. Ultimate consumer activities su as carriers, tenders, self-supporting aircra squadrons, other designated squadrons, crui ers, Reserve Air Stations, FAETU's, Air R serve Training Units, and Marine Servi Squadrons will be designated to submit usa reports. The reports are submitted monthly the Aviation Supply Office. On the activity lev they are submitted by the Maintenance and/ Electronics Officer and approved by the co manding officer.

The report forms consist of a cover pa instruction page, operational data and “ marks” page, usage section, and “write- page. These forms are distributed directl ASO to the activities designated to submit us data. Usage occurring on items not appea in the form will be legibly written-in on blank page provided. To be of value to A utmost care should be exercised in fully ide fying the write-in items reported. Writ items must show the stock number (or ma facturer part number), brief nomenclature, of issue, and quantity used. For avionic “w in” items, identify the usage by part num reference symbol, and major assembly.

Usage data are important and entail a g deal of work. An accounting of materials must be made, so learn what should be and how to do it. The big problem is n filling out the necessary forms, but it is o keeping correct and up-to-date records of the materials that have been used. With proper records you should experience little trouble in fulfilling this administrative responsibility of your rate.

AIRCRAFT INVENTORY LOGS AND RECORDS

An aircraft inventory log or inventory record is used to facilitate the transfer of naval aircraft between activities, giving assurance that the aircraft and its equipment are intact. No aircraft will be transferred or accepted without an inventory log or record. A log or record, as the case may be, is provided for each aircraft and is generally kept by the log section of the maintenance department. Presently, both type reports (log and record) are used by the Navy; however, all new aircraft are provided with the record type report.

The Standard Inventory Log is an official BuWeps publication bearing a NavAer designation applicable to each specific aircraft model. The Aircraft Inventory Record is a Department of Defense publication, and those prepared for the Navy do not bear a NavAer designation.

The log is subdivided into groups of equipment (for example, instrument and navigation, armament, and electronic). The components thereof are listed in alphabetical sequence and according to their location in the aircraft, with the exception of the electronic equipment in which case all units of an equipment are listed in one place regardless of their location in the aircraft. Stock numbers are also supplied for individual items, and are used for ready reference when replacements are required.

The record includes a sectional breakdown diagram of the applicable aircraft. This diagram consists of a side elevation and/or the plan view of a wing, or in the case of twin-boomed or flying wing aircraft, the perspective view. To facilitate inventorying, the sections of the diagram are identified by letters, the letter A being assigned to the foremost section, B to the next, and so on, generally to the rear of the aircraft. The letter R, as part of the item number, denotes items mounted on the exterior of the fuselage, and the letter F denotes items to which access is gained from the fuselage. Subdivisions of sections may be identified by a lowercase letter such as Aa, Ac, and so forth. The equipment list portion of the record is divided into sections, each of which lists the items pertaining to a particular section of the aircraft, as indicated on the sectional breakdown diagram. Within each section, individual items are numbered as nearly as possible in the sequence of their physical location in the aircraft without regard to their relation to specific equipment. Stock numbers are not supplied as part of the equipment listing in Inventory Records.

Standard Inventory Logs are prepared and distributed by the Aviation Supply Office, and are kept as up-to-date as possible. Logs are distributed at the time of acceptance of each new aircraft. Reissues and revisions are distributed directly to the reporting custodians.

The Aircraft Inventory Record is prepared by the applicable aircraft manufacturer, and delivered with each individual aircraft. They are kept up-to-date by the activity to which the aircraft is assigned.

Upon transfer of an aircraft, representatives from the transferring and receiving activities will jointly inventory and record, in the appropriate column provided, the quantity of each item which is ascertained to be on board the aircraft at the time of transfer. In the case of missing items, the transferring activity will make every effort to locate the missing items or to withdraw from store the replacement items necessary to complete the inventory. If it is impossible to locate or supply the missing items, the notation "Missing items are not available" shall be placed on the Report of Inventory Form in the Standard Inventory Log or the Shortages Form in the Aircraft Inventory Record. An explanatory statement signed by the transferring representative shall be placed with this form, indicating the authority for these shortages. On the basis of this statement, the receiving activity will fill the shortages from stock and account for them in the normal manner.

When an aircraft is stricken (disposed of), the Standard Aircraft Inventory Log or Aircraft Inventory Record will normally be destroyed at the time of disposal of the aircraft. In the event that an aircraft is being transferred to other agencies, private concerns, or other governments, and so forth, the inventory log or the record will be transferred with the aircraft as security regulations permit. On occasions when an accident causes strike of the aircraft, the inventory log or the record will be retained by the striking or salvaging activity as long as

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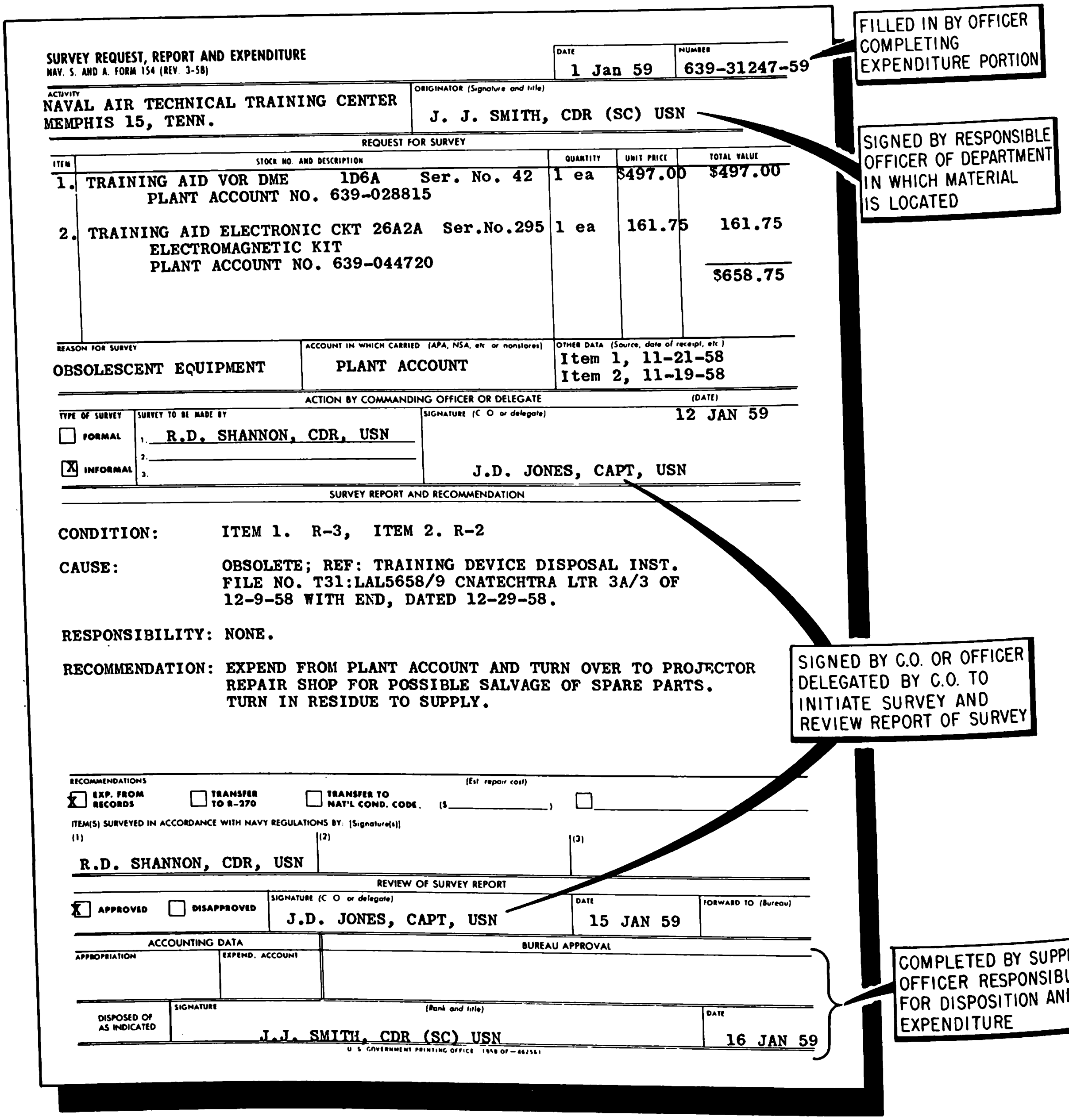
required by authorities conducting the investigation, and then destroyed.

SURVEY OF MATERIAL

When property must be reevaluated or expended from the records due to loss, damage, deterioration, or normal wear a survey must be made to obtain proper authority to write thi material off the books. The survey request pro vides a record showing the cause, condition, re sponsibility, recommendation for dispositio and authority to expend material from the rec ords. Think of a survey as being an administra tive examination into the cause of material bei lost to use. Figure 2-4 shows the standard su vey form that is used when a survey is mad



SURVEY REQUEST, REPORT AND EXPENDITURE
NAV. S. AND A. FORM 154 (REV. 3-58)

DATE: 1 Jan 59
NUMBER: 639-31247-59

ACTIVITY: NAVAL AIR TECHNICAL TRAINING CENTER MEMPHIS 15, TENN.
ORIGINATOR (Signature and title): J. J. SMITH, CDR (SC) USN

REQUEST FOR SURVEY

ITEM	STOCK NO. AND DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL VALUE
1.	TRAINING AID VOR DME 1D6A Ser. No. 42 PLANT ACCOUNT NO. 639-028815	1 ea	$497.00	$497.00
2.	TRAINING AID ELECTRONIC CKT 26A2A Ser.No.295 ELECTROMAGNETIC KIT PLANT ACCOUNT NO. 639-044720	1 ea	161.75	161.75
				$658.75

REASON FOR SURVEY: OBSOLESCENT EQUIPMENT
ACCOUNT IN WHICH CARRIED (APA, NSA, etc. or nonstores): PLANT ACCOUNT
OTHER DATA (Source, date of receipt, etc.): Item 1, 11-21-58 Item 2, 11-19-58

ACTION BY COMMANDING OFFICER OR DELEGATE

TYPE OF SURVEY: ☐ FORMAL ☒ INFORMAL
SURVEY TO BE MADE BY: 1. R.D. SHANNON, CDR, USN 2. 3.
SIGNATURE (C O or delegate): J.D. JONES, CAPT, USN
(DATE): 12 JAN 59

SURVEY REPORT AND RECOMMENDATION

CONDITION: ITEM 1. R-3, ITEM 2. R-2

CAUSE: OBSOLETE; REF: TRAINING DEVICE DISPOSAL INST. FILE NO. T31:LAL5658/9 CNATECHTRA LTR 3A/3 OF 12-9-58 WITH END, DATED 12-29-58.

RESPONSIBILITY: NONE.

RECOMMENDATION: EXPEND FROM PLANT ACCOUNT AND TURN OVER TO PROJECTOR REPAIR SHOP FOR POSSIBLE SALVAGE OF SPARE PARTS. TURN IN RESIDUE TO SUPPLY.

RECOMMENDATIONS: ☒ EXP. FROM RECORDS ☐ TRANSFER TO R-270 ☐ TRANSFER TO NAT'L COND. CODE (Est repair cost) ($______) ☐

ITEM(S) SURVEYED IN ACCORDANCE WITH NAVY REGULATIONS BY: (Signature(s))
(1) R.D. SHANNON, CDR, USN (2) (3)

REVIEW OF SURVEY REPORT

☒ APPROVED ☐ DISAPPROVED
SIGNATURE (C O or delegate): J.D. JONES, CAPT, USN
DATE: 15 JAN 59
FORWARD TO (Bureau):

ACCOUNTING DATA
APPROPRIATION:
EXPEND. ACCOUNT:
BUREAU APPROVAL:

DISPOSED OF AS INDICATED
SIGNATURE (Rank and title): J.J. SMITH, CDR (SC) USN
DATE: 16 JAN 59

U S GOVERNMENT PRINTING OFFICE 1958 OF—462561

FILLED IN BY OFFICER COMPLETING EXPENDITURE PORTION

SIGNED BY RESPONSIBLE OFFICER OF DEPARTMENT IN WHICH MATERIAL IS LOCATED

SIGNED BY C.O. OR OFFICER DELEGATED BY C.O. TO INITIATE SURVEY AND REVIEW REPORT OF SURVEY

COMPLETED BY SUPP OFFICER RESPONSIBL FOR DISPOSITION AN EXPENDITURE

Figure 2-4.—Survey Request, Report, and Expenditure (S. and A. Form 154).

A survey may be either informal or formal, depending on the circumstances.

A formal survey is required for those classes of materials or articles so designated by the bureau or office concerned, or when specifically directed by the commanding officer. A formal survey is made by either a commissioned officer or a board of three members. At least one of the board members must be a commissioned officer. The commanding officer appoints those who serve on the survey. Neither the commanding officer, the officer on whose records the material being surveyed is carried, nor the officer charged with the custody of the material being surveyed, may serve on a survey board.

An informal survey is made by the head of the department having custory of the material to be surveyed. Informal surveys are used in all cases when a formal survey is not required or directed by the commanding officer.

PREPARATION OF REQUEST FOR SURVEY

You will not have the responsibility of preparing final survey forms; however, as a first class or chief, you are apt to be required to provide your division officer with certain information when he is making a survey. Because of this, you should be familiar with the general procedures that are followed.

A request for survey may be originated by a department, division, or section head or a designated subordinate as prescribed by local regulations. Normally, requests for survey are originated in the department having custody of the material being surveyed. The initial survey request is made on a rough copy of S. and A. Form 154. A statement by the originator is placed on or attached to the request for survey relative to the condition of material; cause of condition surrounding the loss, damage, deterioration, or obsolescence of material; responsibility for cause or condition of material or reason why responsibility cannot be determined; and recommended disposition of material or action to be taken.

Upon receipt of the rough copy, the designated group or section prepares a sufficient number of smooth copies of the request for distribution in accordance with local regulations. The smooth survey request is filled out down to the caption Report. It is then forwarded to the commanding officer who will determine whether the survey will be formal or informal. If formal, the survey request is forwarded to the designated surveying officer(s); if informal, it is forwarded to the head of a department for survey action.

The statement by the originator as to cause, condition, and so forth, is attached to the smooth request for survey for evaluation by the surveying officer(s). After the survey has been completed by the head of a department or surveying officer(s), it is returned to the commanding officer for review and action. After approval by the commanding officer, the survey request is forwarded to the cognizant Fleet Command and/or Bureau for final review and approval when so required.

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Publications

As a first class or chief, your responsibilities in connection with installation, adjusting, maintaining, and testing electronic equipment will be much greater than they were when you were a lower rated petty officer. You will be required to have quick and accurate answers to many questions. Since there is a wide variety of this complex equipment, you cannot expect to have a ready answer to all questions. However, you can become familiar with the published materials that contain the answers and by so doing will be able to take positive action. Some of the publications that should prove most helpful will be discussed.

(NOTE: As of 1 December, 1959 the Bureau of Aeronautics and the Bureau of Ordnance were combined as the Bureau of Naval Weapons. Since that date publications are being issued under the new designation of BuWeps; however, publications already issued and bearing the BuAer (Bureau of Aeronautics) designation may remain current for several years. In this chapter the Bureau of Naval Weapons designation will be used in connection with most publications; however, specific reference to existing BuAer publications will remain as originally designated.

The above is also true for publications designated NavAer.)

The training course *AT 3 & 2*, NavPers 10317-A, contains a section on publications. Coverage is given to various handbook publications issued by BuWeps (HMI, HOI, HSI, IPB); general letter publications (BuWeps Instructions and Notices); EMC's and EMB's; specific letter publications (Changes or Bulletins); the *Naval Aeronautic Publications Index;* and the Navy Directives System (Instructions and Notices). This information will not be repeated in this chapter. Note, however, that TO's and TN's, described in *AT 3 & 2*, have been abolished since that source was written.

SPECIFICATIONS AND STANDARDS

Specifications are written to insure that the products manufactured for the Navy meet certain requirements. They are written primarily for the manufacturer; however, the information that they contain can be of much use at the operating or squadron level.

Specifications are clear and accurate descriptions of technical requirements for a material, a product, or service. They include the procedure for determining that the requirements have been met. Specifications do not remain static after issue but are amended or revised as conditions and requirements change. Those that are written for use by the Military Departments will be issued in either the FEDERAL or MILITARY series. They are printed in a standard size, 8 by 10 1/2 inches. Only the military series will be described since most of the specifications that can be of use to you will be this type.

Military Specifications

Military specifications (formerly known as Joint Army-Navy specifications) cover materials, products, or services used only or predominantly by military activities. These specifications were issued first under the auspices of the Joint Army-Navy Specifications Board as JAN specifications. As existing JAN specifications are revised, the prefixes are changed to MIL although the number remains the same.

Military specifications are identified by a symbol composed of three parts. These parts are the letters MIL followed by a single lette which is the first letter of the first word in th title, and a nonsignificant serial number. Mo of the specifications that can be of help to yo are prepared by or under the direction BuWeps. These are intended for use particular in applications to naval aircraft, and as su will be the ones that should be available your activity.

The publication *List of Military Specificatio and Standards* used by the Bureau of Aeronautic NA 00-25-544, is a complete listing of t military specifications and standards used naval aviation. These specifications may be us as an aid in the performance of a particul installation or test; they also provide an e cellent source of information of a gene nature.

Examples of information that may be tained from military specifications listed this publication are as follows:

MIL-STD-704, Electric Power, Aircr Characteristics of
MIL-B-5087A(ASG), Bonding, Electr (For Aircraft)
MIL-W-5088B(ASG), Wiring, Aircraft, stallation of

Military Standards

These include engineering practices, ch categories of dimensional and functional det graphs, formulas, and lists. They are norm issued in book form, but may be in unit form when the standard requires only one s These standards are identified by the sy MIL-STD followed by a hyphen and A numerals assigned to the standard. An exa of a military standard is as follows:

MIL-STD-15A, Electrical and Elect Symbols

The purpose of this standard is to est a uniform system of symbols for use on ings of electric and electronic circu establishes principles governing the for and application of electrical and elec symbols. Also, it provides a list of such bols for electrical and electronic part assemblies or subassemblies shown on dia (wiring, schematic, and so forth).

TYPE COMMAND BULLETINS AND INSTRUCTIONS

The final operational control of naval aviation rests with the Fleet and Task Force commanders. Yet, in a sense, the Commanders Naval Air Force U. S. Pacific Fleet and Atlantic Fleet direct naval aviation. They establish policies regarding the organization, maintenance, and employment of fleet aviation; study the strategic situation and make recommendations concerning the distribution of naval air forces; and advise the Fleet commanders on air operations. Type commanders (COMNAVAIRPAC and COMNAVAIRLANT) are responsible for overhaul and maintenance of aircraft and supplies, for squadron training, and for the preparation of operational doctrines for all types of aircraft. In performing these functions COMNAVAIRPAC and COMNAVAIRLANT maintain close liaison with DCNO (AIR) and the Bureau of Naval Weapons.

Type commanders issue technical publications, usually in letter or directive form, that contain information for maintenance personnel. Bulletin type releases are usually used in promulgating this information. As of June 1957, COMNAVAIRPAC information was released in one of the following types of bulletins:

CATEGORY	
General Aircraft Bulletin.	GAB
Model Aircraft Bulletin	AB
General Engine Bulletin.	GEB
Model Engine Bulletin	EB
Special Weapons Bulletin	SWB
General Avionics Bulletin	GAVB
Aircraft Model Avionics Bulletin.	AVB
Catapult and Arresting Gear Bulletin . .	CAGB
General Support Equipment Bulletin. . .	GSEB

Bulletins are numbered consecutively for one-year periods and include the calendar year. A bulletin for each of the various categories is published during January which lists all effective bulletins.

SOURCES OF INFORMATION

There are a great number of publications that pertain to your work. If properly used, they provide very useful information that can be of much help. It is the responsibility of your command to make these publications available to you. It is your responsibility to see that they are adequately used.

The following sources of information, with brief descriptive statements, should prove helpful and are given as a ready reference. A suggested method whereby general interest materials may be readily available is to place them in suitable binders and keep them in the shop.

U. S. Navy Safety Precautions, OpNav 34P1

This publication is a rather complete text on the subject of naval safety and is the result of compiling all directives and publications previously issued on the subject. All supervisory personnel should become familiar with the chapters dealing with aviation and the chapter on electricity and electronics.

Substitution Guide for Electron Tubes, Transistors, and Rectifying Crystals

This publication is a part of the Navy Stock Lists. It is Section FSC 596 (Federal Stock Catalog) of the Electronics Supply Office catalog. As the title implies, it is a guide that may be used to determine what respective tubes, transistors, or rectifiers may be used interchangeably. Directions to be followed when locating a substitute item are included on the back side of the cover sheet.

Handbook of Operation and Service Instructions on AN Electrical Connectors, AN 03-5-90

This handbook covers the description, selection, preparation, installation, and maintenance instructions for commonly used AN connectors. It may serve as a source of general information for the technician and also as a training guide for those inexperienced in the construction of cables using AN connectors.

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Index-Transmission Lines and Fittings, NavShips 900-102B (ASESA 49-29A)

This publication contains charts and tables which aid in the selection of proper cables and fittings to be used in constructing coaxial lines.

Reduction of Radio Interference In Aircraft, NavAer 16-1-521

The purpose of this manual is to present information which will serve as a guide to the aviation industry and to naval aircraft maintenance activities for achievement and maintenance of the lowest practicable level of radio interference in naval aircraft. It may be used as a guide to enable you to determine the type of interference, to locate its source, and to provide a means for its elimination or suppression. The information is presented under the following headings:

1. Purpose.
2. Types and Effects of Radio Interference.
3. Sources of Radio Interference.
4. Interference Coupling.
5. Basic Installation Planning for Radio Interference Control.
6. Radio Interference Reduction Components; Their Selection, Application, and Installation.
7. Bonds and Bonding.
8. Shields and Shielding.
9. Testing for Radio Interference.
10. Maintenance Aspects of Radio Interference.

Handbook, Aircraft Inspection Requirements

These handbooks contain complete requirements for periodic maintenance inspections and periodic replacement of accessories and components applicable to the aircraft to which the handbook pertains. They are used in the preparation of check sheets. These handbooks are of two types—(1) the *Handbook of Inspection Requirements Daily and Preflight* and (2) the *Handbook of Inspection Requirements Intermediate and Major*. Such handbooks are published for each particular model aircraft.

The *Handbook of Inspection Requirements Daily and Preflight* is composed of the master copy of the Daily and Preflight Inspection Check Sheet(s) for that aircraft. These check sheets break down the daily and preflight inspection by aircraft sections and systems.

The *Handbook of Inspection Requirements Intermediate and Major* is composed of two parts. Part 1 contains general instructions, definitions, special inspections, replacement schedules, and a listing of applicable references. Part 2 is a master copy of the Intermediate and Major Inspection Check Sheet (s), organized by systems, including entry space for additional work to be performed, discrepancies noted and corrected, and parts added and removed during the inspection.

Handbook of Installation Practices for Aircraft Electric and Electronic Wiring, NavAer 01-1A-505

This handbook was written for the followin purposes.

1. To gather together under one cover th recommended practices and techniques to b used for installing, repairing, and maintainin aircraft electric wiring.

2. To standardize these techniques an methods so that electrical installations will b done in a uniform manner.

3. To indoctrinate all personnel with th importance of good workmanship.

4. To point up the failures which may resu from poor workmanship.

5. To promote safety by pointing out a prohibiting unsafe practices.

The information contained in the handbo represents the best current knowledge a practice in the aircraft electrical field. It h been compiled with the cooperation and assi ance of the country's leading airframe ma facturers, airline operators, and military ov haul and repair bases. Many of the illustrati have been provided by the manufacturers electrical accessories used in aircraft.

The topics covered are (1) wire and ca preparation, (2) general purpose connecto (3) RF connectors and cabling, (4) solder terminations and splicings, (5) thermoco wire soldering and installation, (6) bonding grounding, (7) bus bar preparation, (8) co fabrication, (9) installation of bus bars, con junction boxes, protective devices, and term strips, (10) electrical wiring installation, lacing and tying, (12) safety wiring, and emergency repairs.

Copies of this handbook should be readily available in the electronic shop. It can be of much assistance to the leading petty officers for it contains the answers to many special maintenance problems. Also, it is an excellent source of information for the strikers and lower rated men and you should use it as a teaching aid in carrying out your on-the-job training duties.

Naval Aeronautic Publications Index, NavWeps 00-500, NavWeps 00-500A, NavWeps 00-500B

This index is composed of three parts (three separate publications). A description of each part is given in the Navy Training Course *AT 3 & 2,* NavPers 10317-A, and will not be repeated here. Attention is given to the index in this course because with all probability, it can be of more help to you as a first class or chief than any other publication. For example, the information in the index can be used for determining what equipment is installed in a particular aircraft, for obtaining code numbers and titles when preparing orders for publications, and for many other uses. It contains a complete numerical listing of almost all of the publications that you will need in connection with aircraft electronics maintenance.

You must know how to properly use the index in order to obtain the best results. Instructions are contained in the front part of each section. By carefully studying these instructions and familiarizing yourself with the total contents of the index you will have a knowledge of the many uses that it can serve.

Aviation Electronics Officer's Guide, NavAer 00-80T-64

This publication is issued by the Office of the Chief of Naval Operations, Aviation Training Division. It is a compilation of information prepared primarily to assist the naval aircraft electronics officer in the performance of his technical and administrative duties. Since some of the duties of the ATC and AT1 closely parallel those of the electronics officer this publication can be of use as an excellent source of information.

The major sections of the publication are as follows: introduction to naval aeronautics organization; safety; technical duties; reports, records, local directives and memoranda; supply; publications; education and training; security; and technical reference material.

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QUIZ

1. The aircraft inventory record is
   a. a Department of Defense publication
   b. prepared by the Aviation Supply Office
   c. prepared by the Bureau of Naval Weapons
   d. a BuAer Publication bearing a NavAer designation applicable to each specific aircraft model

2. Which of the below items is NOT a function of source coding?
   a. Indicating where an item is stored
   b. Use of the next higher assembly
   c. Part to be locally manufactured
   d. Part is obtainable in supply system

3. The seven-digit group of a federal stock number
   a. indicates the cognizant bureau or office
   b. indicates storage location of item
   c. is serially assigned when material item is identified
   d. designates federal classification

4. The Naval Aeronautic Publications Index contains a listing of
   a. almost all current electronics maintenance publications
   b. all BuPers publications
   c. military specifications used by the Bureau of Naval Weapons
   d. military information applicable to aircraft

5. Which of the following is a material reliability report?
   a. MRR
   b. FUR
   c. RUOM
   d. BuAer reliability digest

6. The Handbook of Installation Practices for Aircraft Electric and Electronic Wiring was written
   a. to promote safety
   b. to indoctrinate all personnel with good workmanship
   c. to point out failures resulting from poor workmanship
   d. all of the above

7. Electron tubes are controlled by the
   a. ASO
   b. ESO
   c. fleet command
   d. local command

8. The purpose of the material reliability program is to
   a. develop a historical record of material failures
   b. fix the blame for material failures
   c. perform statistical and technical analysis of equipment failures
   d. insure fleet awareness of material reliability

9. The Navy Stock List is a catalog of
   a. aviation stores
   b. general stores
   c. all Navy stores
   d. all federal stores

10. The designation of items as fleet-controlled material is based on information submitted by
   a. BuWeps
   b. Fleet commands
   c. ASO
   d. ESO

11. Ultimate consumer activities (carriers, NAS's, FAETU's, etc.) submit maintenance usage data reports
   a. every ninety days
   b. every two weeks
   c. every six months
   d. each month

12. Which of the below is a direct function of ASO?
   a. Issuance of aviation material
   b. Publication of Federal Cataloging Systems
   c. Procurement of aviation materials
   d. Storage of aviation material

13. A formal survey board must include
   a. at least five persons, one of whom must be a commissioned officer
   b. one or more commissioned officers
   c. three members appointed by the custodian plant account records
   d. one enlisted man

14. Specifications and standards are written primarily
   a. for the manufacturer
   b. for the operating activities
   c. to insure that products manufactured for the Navy meet certain requirements
   d. to enable O & R activities to more efficiently overhaul and repair aircraft

15. For obtaining its aeronautical materials an aircraft carrier would be assigned t a ________ stock point.
   a. reserve
   b. distribution
   c. secondary
   d. primary

16. The Section B allowance list is compile and distributed by
   a. ASO
   b. BuSandA
   c. BuWeps
   d. the federal cataloging system

17. Cognizance control symbol R is assigned
   a. ASO
   b. ESO
   c. BuWeps
   d. Forms and Publications Supply Offi

18. When property is to be re-evaluated expended from the records
   a. a survey must be made to obtain prop authority to write the material off books
   b. a request is turned in to the Mater Office and equipment is turned in class 265 for screening
   c. information to show condition of equ ment must be submitted to the main nance officer
   d. A FUR or EFR should be made out the equipment

19. Military standards contain information t relates to
   a. products or services used only by m tary activities
   b. information formerly contained in J Army-Navy Specification
   c. engineering practices, charts, grap formulas, and lists
   d. information obtained from mili specifications

20. Supply lists that are used when commissioning or reactivating an activity are referred to as
    a. usage data lists
    b. Navy Stock Lists
    c. availability lists
    d. allowance lists

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CHAPTER 3

RC AND RL NETWORKS

Electronic equipment that is used in present day naval aircraft is complex and everchanging. Aviation electronic equipment is used for communications, navigational aid, search, fire control, aircraft identification, and numerous other functions. The information presented in this and the following chapters is for the purpose of aiding you in gaining an understanding of these various equipments.

For the most part, the circuits discussed are common to electronic equipments that the technician will be required frequently to maintain and operate. Only in a few cases will circuits peculiar to a particular piece of equipment be used.

Many of the circuits in electronic equipment are concerned with timing and control. Circuits accomplish this function by producing a variety of voltage waveforms, such as square waves, sawtooth waves, trapezoidal waves, rectangular waves, brief rectangular pulses, and sharp peaks. In sound and in radio, tubes operate within the limits for which they are designed. In timing circuits, they often are violently overdriven, frequently operating at points which range from well in the grid current region to far beyond cutoff. Although all these circuits are broadly classified as timing circuits, the specific function of any individual circuit might be timing, waveshaping, or wave generating. This chapter discusses the principles of a variety of timing circuits, and provides a foundation for understanding the operation of specific circuits.

TRANSIENT AND NONSINUSOIDAL VOLTAGES

Most of the waveshapes in timing circuits are produced by combinations of vacuum tubes, resistors, capacitors, and inductors. For example, the rate of charging and discharging of capacitors and inductors make these elements extremely useful in timing circuits because of their effect on transient and nonsinusoidal voltages.

A transient nonsinusoidal voltage is a brief voltage change called a pulse which occurs once and does not recur for a comparatively long time. Such a voltage change is never sinusoidal but is usually periodic; that is, the change repeats itself at regular intervals. Examples of typical transient voltages are compared to a periodic sine wave in figure 3-1.

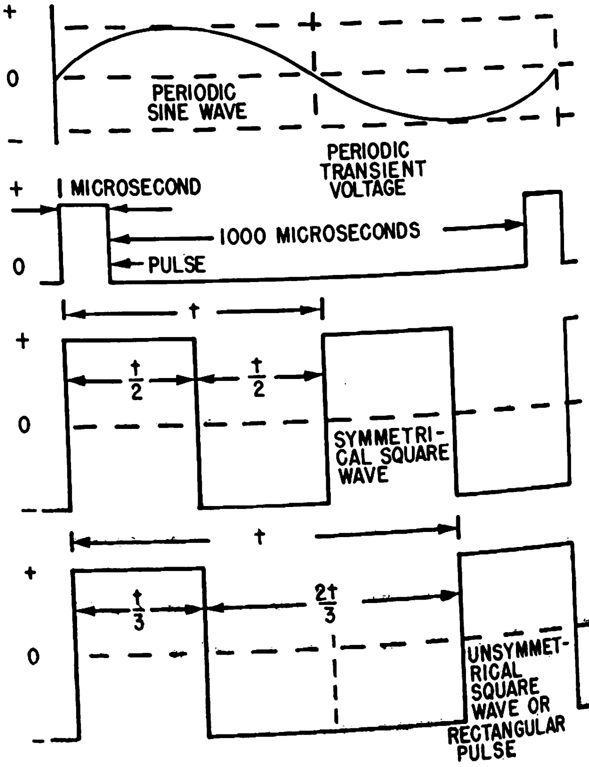

Figure 3-1.—Examples of transient voltages

Analysis

For the purpose of circuit design, there
two ways of analyzing transient nonsinusoi
voltages. One is to consider that the transi

waveshape is merely a rapid change of voltage, which may be followed after a certain interval by another and similar change. The other is to assume that the waveshape is the result of the addition of a large number of sine waves having different frequencies and amplitudes. The second method of analysis is more useful in most cases. In the design of an amplifier, for example, this type of analysis is necessary because the amplifier cannot handle a transient without distortion unless it is capable of handling all the sine-wave frequencies making up the transient. This analysis explains why a square wave applied to an amplifier circuit may suffer distortion. If the circuit cannot amplify the high frequencies, then the square wave will have rounded instead of square corners.

Transient voltages have many different and complex shapes. The more commonly used transient waves are the square wave, the sawtooth or triangular wave, and the peaked wave.

The Square Wave

Figure 3-2 (A) shows a square wave in which voltage is plotted against time. This wave is called SYMMETRICAL because the alternations are identical.

In terms of the first method of analysis stated in the preceding paragraph, consider the square wave in the illustration as a voltage which remains unchanged at plus 50 volts until time t_1, when it suddenly changes to minus 50 volts; it remains at this value until time t_2, then suddenly rises to plus 50 volts and remains at this value until time t_3, and so on.

In terms of the sine-wave method, analyze the square wave by determining what sine waves are required to reproduce it. To reproduce a symmetrical square wave, start with a sine wave which is equal in frequency to the square wave repetition frequency, and add to it the odd harmonics of this frequency as shown graphically in (B), (C), and (D) of figure 3-2. The waveshape C is formed by adding the fundamental frequency A and its third harmonic B which has an amplitude one-third that of the fundamental. (See fig. 3-2 (B).) Notice that the resultant wave already slightly resembles a square wave as can be seen by the square wave superimposed on the diagram. The result of adding the 5th harmonic of the fundamental frequency to the resultant wave C is shown in figure 3-2 (C). Notice in the resultant wave E that the corners are much sharper and the top somewhat flatter.

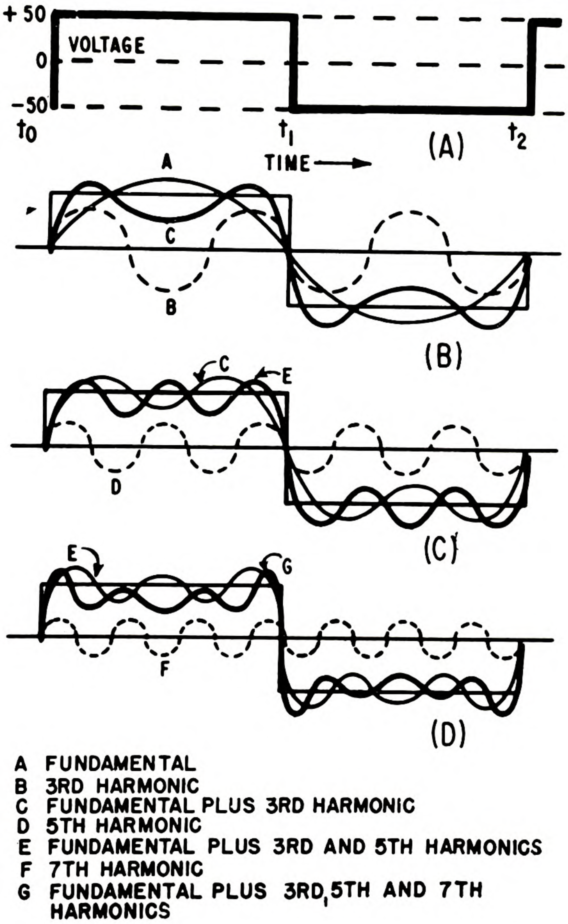
+50
0
-50
VOLTAGE
t_0
t_1
t_2
TIME ⟶
(A)
A
C
B
(B)
C
E
D
(C)
E
G
F
(D)
A FUNDAMENTAL
B 3RD HARMONIC
C FUNDAMENTAL PLUS 3RD HARMONIC
D 5TH HARMONIC
E FUNDAMENTAL PLUS 3RD AND 5TH HARMONICS
F 7TH HARMONIC
G FUNDAMENTAL PLUS 3RD, 5TH AND 7TH HARMONICS

Figure 3-2.—Composition of symmetrical square wave.

The 7th harmonic at 1/7 amplitude is added to form the resultant curve G (fig. 3-2 (D)). This curve is fairly smooth across the top and fairly sharp at the corners. Adding the 9th harmonic at 1/9 amplitude, the 11th harmonic at 1/11 amplitude, etc., would further sharpen the corners and flatten the top of the wave.

The assumption that a square wave contains a number of frequencies, although it is actually just a change of voltage, is useful in studying the square wave in circuits. For example, according to the frequency method of analysis, the higher harmonics are responsible for the sharpness in the corners of the square wave. Therefore, if a circuit rounds off the corners of a square wave it can be said that the circuit has discriminated against (refused to pass) the higher frequencies. Furthermore, since this method of analysis reduces a square wave to

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terms of sine waves of different frequencies, it is possible for engineers to design circuits by using conventional sine-wave engineering practices.

Most square waves employed in electronics consist of short pulses separated by long time intervals. (See fig. 3-3 (A).) Such pulses are constructed in the same way as square waves, but in addition to the sine waves of the fundamental pulse frequency and many harmonic frequencies of fractional amplitudes, a small d-c voltage is required. The duration of the pulse is one-third of the repetition time which, in this case, is 1,000 times per second (fig. 3-3 (A)). To reconstruct this pulse, add a d-c voltage equal to one-third the desired pulse amplitude to a 1,000 c.p.s. sine wave having an amplitude two-thirds of the pulse amplitude. Then add a 2,000 c.p.s. sine wave having an amplitude one-third of the pulse amplitude, and so forth. The solid curve (fig. 3-3 (B)) represents the sum of all these voltages. Notice that there is a rough resemblance between the outline of the solid curve and the desired square wave. Add all the harmonics up to about the 15th harmonic (15,000 c.p.s.) in the proper phase and amplitude; the resultant waveshape will be quite square.

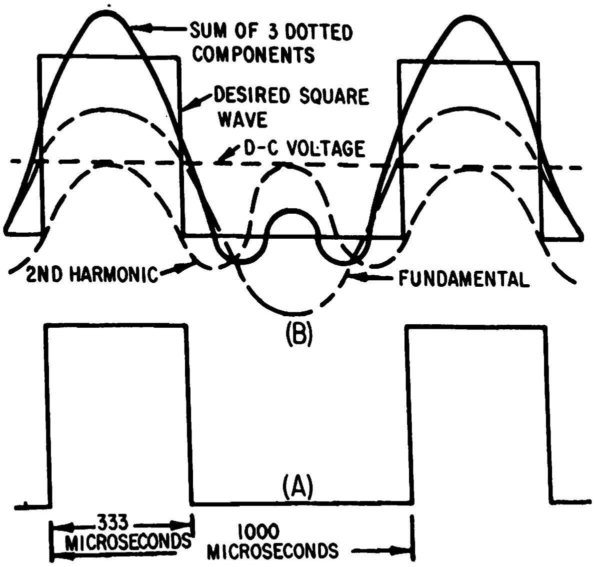

Figure 3-3.—Composition of square wave with short duration pulses.

An important fact to consider is the number of harmonics to include in forming the waveshape. The rule to follow is that the maximum number varies inversely with the pulse width. This means the wider the pulse, the smaller the number of harmonics, and inversely, the narrower the pulse, the greater the number of harmonics. For example, in figure 3-3 the width of the pulse is such that the first 15 harmonics can be included.

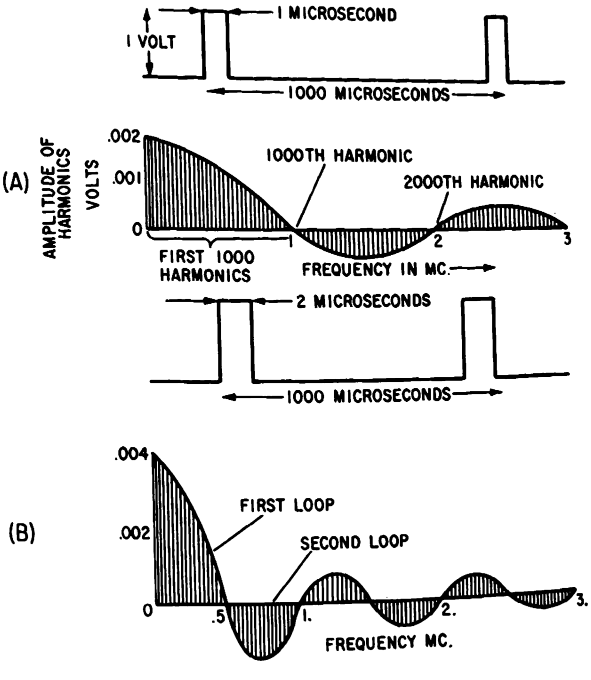

Figure 3-4.—Harmonic content of short square pulses.

In figure 3-4 a much narrower pulse is sho a one-microsecond square wave having a r peating frequency of 1,000 c.p.s. This pulse r quires a great many more harmonics, as can seen in (A) of figure 3-4. Here, the amplitu of each harmonic is plotted on the Y axis, a its frequency is plotted on the X axis. The to of all the vertical lines are connected by a cu which forms a sine wave. It is impossible to sh all the frequencies, since 1,000 harmon actually occur between zero and 1 megacyc

When the pulse amplitude, as shown in fig 3-4, is one volt, the damped sine wave produ by connecting the amplitudes of the harmonic less than 0.002 volt. The relative importance the various frequencies depends upon the a under the sine-wave curve, varying with the s of the area. Notice that the largest area occ between zero and 1 mc. The significance of is that any circuit which does not discriminate against any frequency from 1,000 c.p.s. to 1 mc. will pass this pulse with little distortion.

Figure 3-4 (B) shows that doubling the pulse width to two microseconds causes the amplitude of the harmonic frequencies to drop to zero at a half megacycle. Thus, any circuit designed for operating with a two-microsecond width will not discriminate against any frequency from 1,000 c.p.s. to 500,000 c.p.s.

All this leads to the conclusion that there is a certain relationship between the highest frequency that a circuit can handle and the width of the pulse. For example, in the case of the one-microsecond pulse, the highest frequency was 1 mc., and in the case of the two-microsecond pulse, 1/2 mc. The rule is that frequency varies inversely with pulse width. Mathematically this is expressed as,

$$F_h = \frac{1}{PW}$$

where F_h is the highest frequency for the circuit, and PW the pulse width in microseconds when the pulse width is much smaller than the pulse repetition period.

Note that the pulse repetition frequency is not considered in the equation, since it is quite evident also by transient analysis that the pulse recurrence frequency has nothing to do with the harmonic frequencies in the pulse. For example, if the repetition frequency changed to 500 c.p.s. (fig. 3-4 (B)), there would be twice as many harmonic frequencies in the first loop, but the loop would still pass through zero at 0.5 mc.

The lowest frequency that this circuit must be able to handle is the fundamental or the pulse repetition frequency. However, several of the low-frequency harmonics can be removed from the curves without noticeably reducing the areas. (See fig. 3-4 (A) and (B).) Thus, a circuit may be designed for a one-microsecond pulse and handle a frequency band as narrow as 10 kc. to 1 mc.

Triangular and Sawtooth Waves

Triangular and sawtooth waves, like square waves, can be constructed with a series of sine waves. Circuits designed to handle the short sawtooth wave shown in (C) of figure 3-5 must have about twice the bandwidth as a circuit required for a square pulse of the same dimensions.

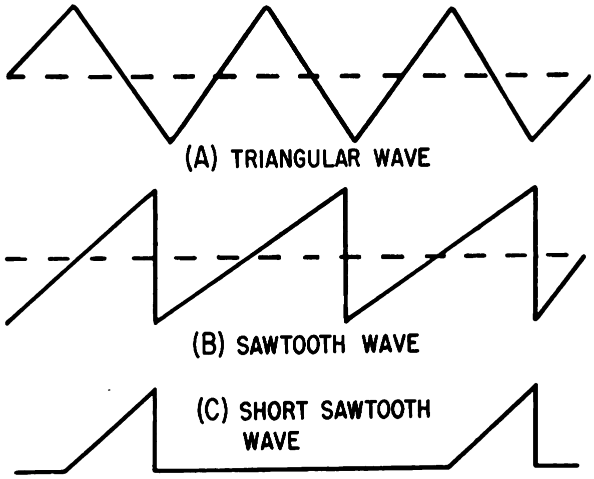

Figure 3-5.—Triangular and sawtooth waves.

COMPOSITION

A sawtooth wave contains both odd and even harmonics. The wave shown in (D) of figure 3-6 contains all the harmonics up to the 7th. Notice how closely this wave resembles the sawtooth wave superimposed on it.

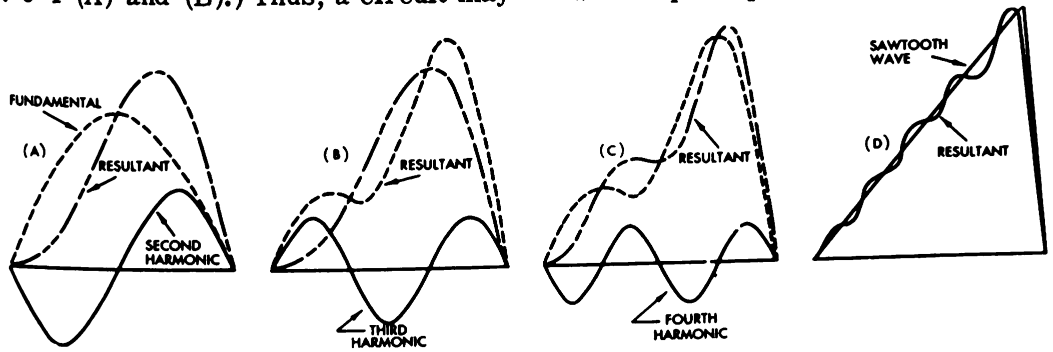

Figure 3-6.—Composition of sawtooth wave.

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From the viewpoint of a transient voltage, consider the sawtooth voltage wave to be a slow linear voltage change from an initial value to a certain higher value, followed immediately by a sudden drop to the initial value. The wave may repeat immediately, or after an interval of time has elapsed.

Peaked Waves

A peaked wave is another wave which can be constructed with a number of sine waves. Figure 3-7 shows how the addition of successive odd harmonics to a fundamental sine wave produces a peaked wave. First, the 3rd harmonic, a wave having a lower amplitude, is added to the fundamental. Next, the 5th harmonic is added to wave C. This produces wave E in which the peak is further heightened and the sides further sloped. This process, if carried further, will produce a wave with higher and higher peaks and steeper and steeper sides.

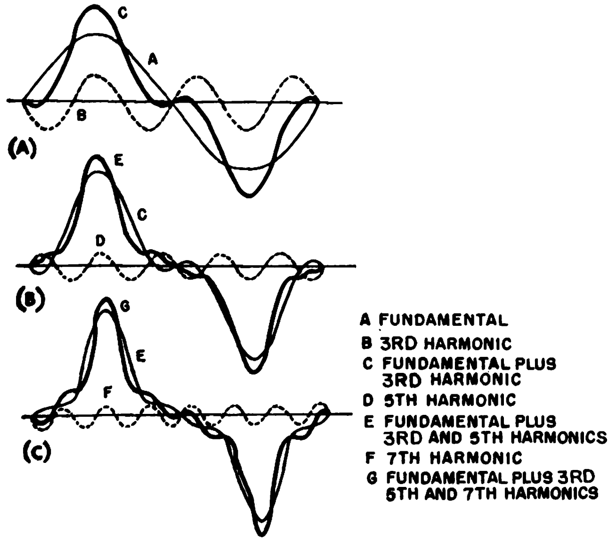
C
A
B
(A)
E
C
D
(B)
G
E
F
(C)
A FUNDAMENTAL
B 3RD HARMONIC
C FUNDAMENTAL PLUS 3RD HARMONIC
D 5TH HARMONIC
E FUNDAMENTAL PLUS 3RD AND 5TH HARMONICS
F 7TH HARMONIC
G FUNDAMENTAL PLUS 3RD 5TH AND 7TH HARMONICS

Figure 3-7.—Composition of a peaked wave.

The composition of a peaked wave differs from that of a square wave in that there is a different phase relationship between the harmonics. In the square wave composition all the odd harmonics cross the zero line in phase with the fundamental. In the peaked wave composition the 3rd, 7th, 11th, and so forth, harmonics cross the zero line 180 degrees out of phase with the fundamental while the 5th, 9th, 13th, and so forth, cross the zero line in phase with the fundamental.

TRANSIENT VOLTAGES IN RC CIRCUITS

RC Time Constant

The characteristics of the waveforms required by special circuits, such as slope, duration, or repetition frequency, are determined largely by controlling the variation of a voltage with respect to time. Since the charging or discharging of a capacitor through a resistor requires time, resistance-capacitance circuits are commonly used for this purpose.

To learn how a resistor-capacitor circuit affects a waveshape applied to it, it is well to investigate first the voltage and current changes which occur when a d-c voltage is applied to the circuit. Most RC circuits and the voltages applied to them are reducible to a simple equivalent circuit containing a battery, capacitor, and resistor.

Figure 3-8 (A) shows such a simple series circuit. According to capacitor theory, the capacitor C will offer zero resistance to the direct-current flow in the circuit at the instant the switch is closed. Therefore, at the first instant after the switch is closed, current in the circuit is maximum. Later the capacitor C will offer infinite resistance, since it charges to a voltage equal and opposite to the battery voltage E_{bb} after a period of time. When the capacitor is charged, the battery voltage is canceled completely, leaving no voltage to cause a current to flow through the resistor. However, before the current does reach zero, there is a lapse of time. This lapse provides the time element required in the formation of many different waveshapes.

To understand how a capacitor affects the time delay in a circuit, first consider what happens in the capacitor itself, and how it is affected by the rest of the circuit. Assume that before you close switch Sw, the capacitor is completely discharged—that is, there is an equal number of electrons on each of its plates. The voltage charge on a capacitor, and its polarity are determined by the ratio of electrons on th capacitor's plates. The plate with an excess o electrons will be negative. Addition of electron

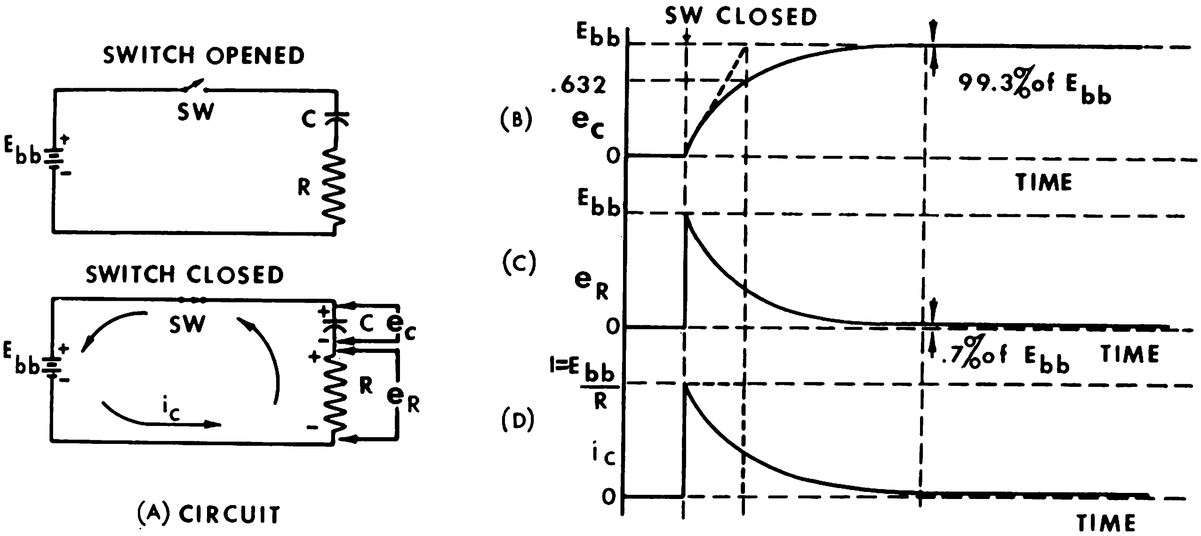

Figure 3-8.—Current and voltage during capacitor charge.

means a higher voltage change on the capacitor. When you close the switch, the battery voltage E_{bb} immediately forces electrons into the capacitor plate connected to the negative terminal of the battery, placing a negative charge on it. This creates a stress on the dielectric which, in turn, forces electrons away from the other plate and makes its charge positive.

It might seem that if it were not for the limiting effect of the series resistor, the number of electrons that would accumulate on the capacitor plate would be infinitely high because, upon closing of the switch, the current in the circuit would immediately jump from zero to a value determined only by the resistor. (That is, $i = \frac{E_{bb}}{R}$ since the uncharged capacitor offers no opposition to current flow.)

The fact is, however, that the capacitor itself offers opposition to the current. Just as soon as a few electrons accumulate on a capacitor plate, there is a like number forced away from the other plate. The net result is a small voltage difference across the capacitor, the plate with more electrons being the negative point of voltage, and the plate with less electrons being the positive point of voltage. The polarities of the circuit then become as shown in (A) of figure 3-8. Notice here that the capacitor is charged to a voltage opposite in polarity to the battery voltage. Thus, in a short time after closing the switch, the movement of electrons—that is, current flow—does not remain at its initial value, but drops to a lower value because the instantaneous voltage across the capacitor subtracts from the battery voltage. Since the voltage applied to the capacitor is thus progressively reduced, the capacitor charges at a progressively slower rate.

Values of Capacitor and Resistor Voltages

There are three methods of determining the instantaneous values of voltage across capacitors and resistors in RC circuits. The first is a rough estimate from the exponential curve with the values at four main points known. The second is a close approximation from a very accurate exponential curve on a universal time constant chart. The third involves solving the equation for the curve with quantities for the RC problem inserted in the equation.

ROUGH APPROXIMATION CURVES

The voltage or current at any instant during the charging time of a capacitor can be approximated from the two curves shown in figure 3-9. These curves employ only rough values, but they are useful for approximating current at any instant during the charge of a capacitor. To find current, substitute the total current flow in the circuit for E_{bb} on the curves. Ten time constants is assumed to be the time necessary for the capacitor to charge to 100 percent.

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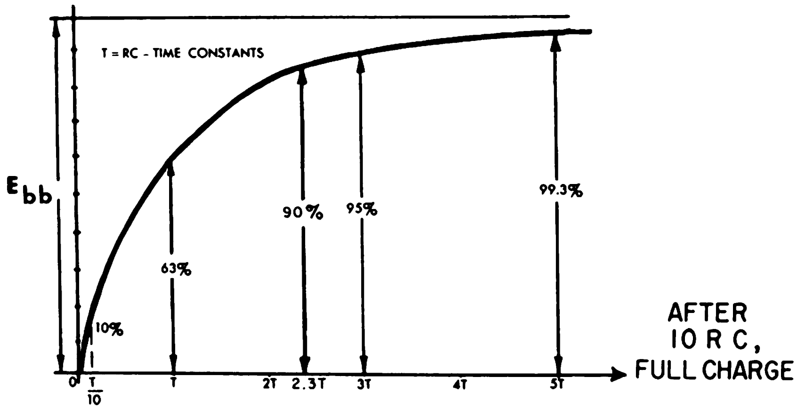
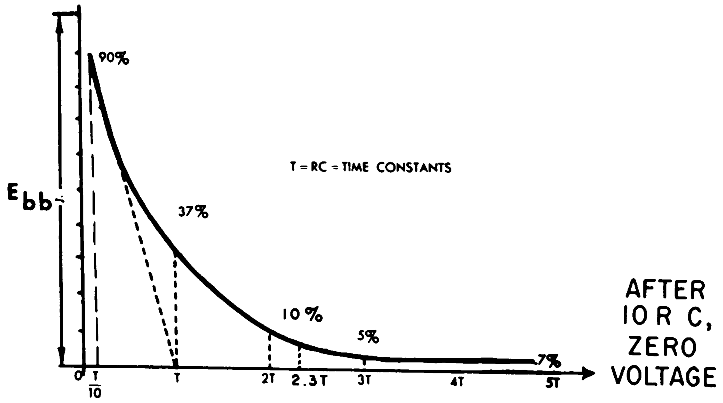


(A) CURVE FOR CAPACITOR VOLTAGE DURING CHARGE



(B) CURVE FOR RESISTOR VOLTAGE DURING CHARGE

Figure 3-9.—Exponential curves for rough approximations.

UNIVERSAL TIME CONSTANT CURVES

A universal time constant chart (fig. 3-10) provides a much more precise method for determining the voltage and the current at any instant during the charge of a capacitor than the method just described. The chart shows a number of time constants plotted against the fraction of maximum current or voltage.

In learning to use this chart study the following examples:

PROBLEM 1.—In the circuit in figure 3-11, assume that C equals 0.001 μf. and that R equals 100K. Find the capacitor voltage 200 microseconds after the switch is closed.

Solution:

a. Find the time constant.

t.c. = RC
t.c. = 100,000 x 0.001
t.c. = 100 microseconds

b. Since 200 microseconds is equivalent t time constants, enter the universal ti constant chart at 2 along the bottom and p ceed up to curve A. (This curve represe the capacitor charge voltage.) At curve proceed horizontally to the vertical sc and read 0.86. This represents the fract of maximum voltage.

c. Thus, the capacitor voltage is about 86 p cent of maximum. With 200 volts as the plied voltage, the capacitor voltage eq

200 x 0.86 or 172 volts.

PROBLEM 2.—In the same circuit find resistor voltage 200 microseconds after switch is closed.

Solution, using Kirchhoff's law:

From the previous example, the capa voltage equals 172 volts.

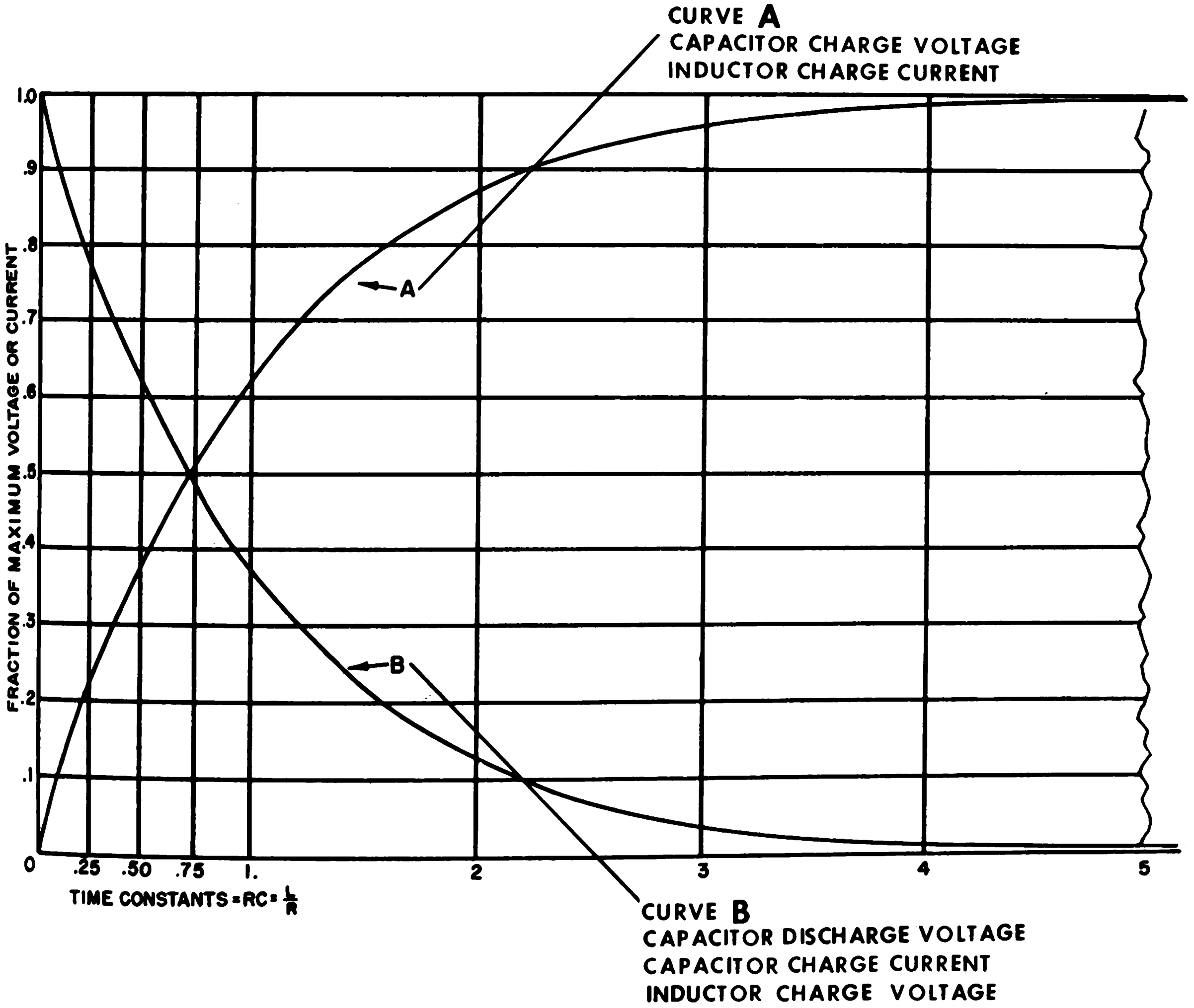


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Figure 3-10.—Universal time constant chart.

Since the circuit is a series circuit, the resistor voltage is the difference between the applied voltage and the capacitor voltage. Thus,

200 - 172 = 28 volts.

Solution, using the universal time chart: Knowing that the resistor voltage starts high and then drops off, you use curve B. Since there are two time constants involved, go up from 2 to curve B and then across the vertical scale. At the intersection you find 0.14. Since the applied voltage is 200 volts, the resistor voltage must be

200 x 0.14 or 28 volts.

Solution:
Using universal chart; find current.
By Ohm's law the maximum current is

$$\frac{200}{100K} \text{ or } 2 \text{ ma.}$$

At two time constants, the current is 0.14 of maximum, according to curve B and the scale at the left. Therefore,

0.14 x 2 ma. = 0.28 ma.

By Ohm's law

$$E = IR$$

The instantaneous voltage is

0.28 ma. x 100K = 28 volts.

PROBLEM 3.—In the same circuit find how long it takes for the resistor voltage to drop to 120 volts.

Solution:

$$120 \text{ volts} = \frac{120}{200} \text{ or } 0.6 \text{ of } 200 \text{ volts.}$$

Find 0.6 on the vertical scale, then go to curve B, thence down to 0.5 time constants. If one time constant equals 100 microseconds, the time required for the resistor voltage to drop to 120 volts must equal

0.5 x 100 or 50 microseconds.

NOTE: Any value of voltage and any size of resistor or capacitor can be used with the universal time constant chart. After 10 time constants the capacitor is considered to be fully charged, and the resistor voltage and the circuit current are considered to be zero as shown in figure 3-11.

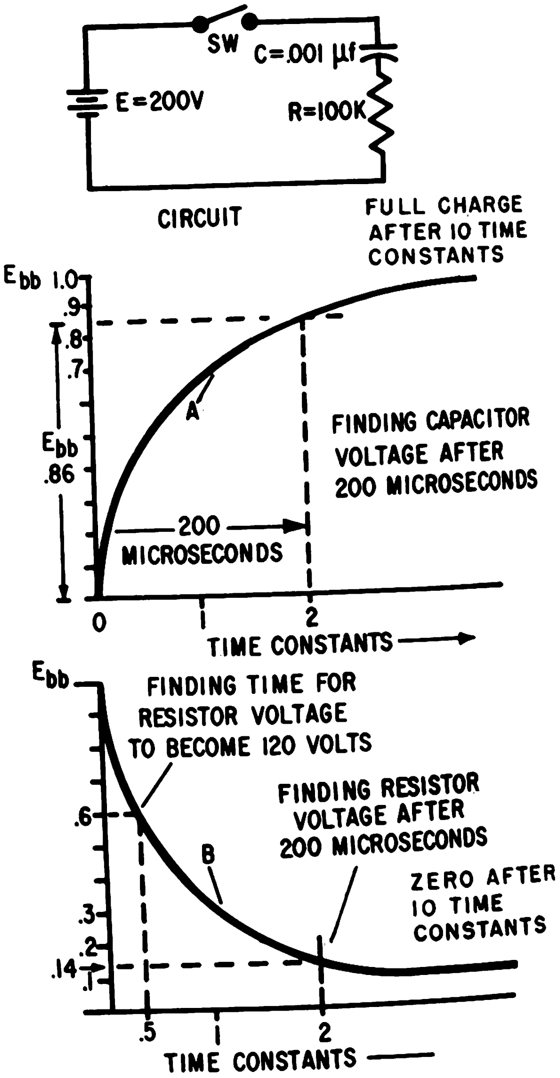

Figure 3-11.—Using universal time constant chart.

Capacitor Discharge Through Resistance

The discharge of a capacitor through a resistor follows the same exponential curve as the charge through a resistor. (See fig. 3-12.) When the capacitor is charged to a voltage of E_C, there is an excess of electrons on one plate of the capacitor. This unbalanced condition causes a potential difference which exists as long as the switch is open (assuming the capacitor is perfect). The portions of the curves indicating an open switch condition show that the capacitor voltage is E_C, the current in the circuit is zero, and the resistor voltage is also zero.

When the switch is closed, the electrons on the negative plate immediately surge through the circuit toward the other capacitor plate, building up a current which is limited to a value determined by Ohm's law; that is, a value equals to $\frac{E_C}{R}$. This is what happens. The initial current causes a voltage drop across the resistor equal to the capacitor voltage. But as soon as current flows, the number of excess electrons causing the current flow decreases. This caus a voltage decrease. The decrease is not linea however. The high initial current decreases t voltage rapidly, but subsequent lower voltag cause lower currents, which remove the char at a lower rate. The discharge becomes slow and slower until at the end of 5 time constan the current is less than 1 percent of the init value. The voltage causing this low current also extremely low because the capacitor 99.4 percent discharged. Theoretically, time required to discharge the capacitor is finitely long, but for practical purposes, time constants may be considered as the ti required for complete discharge.

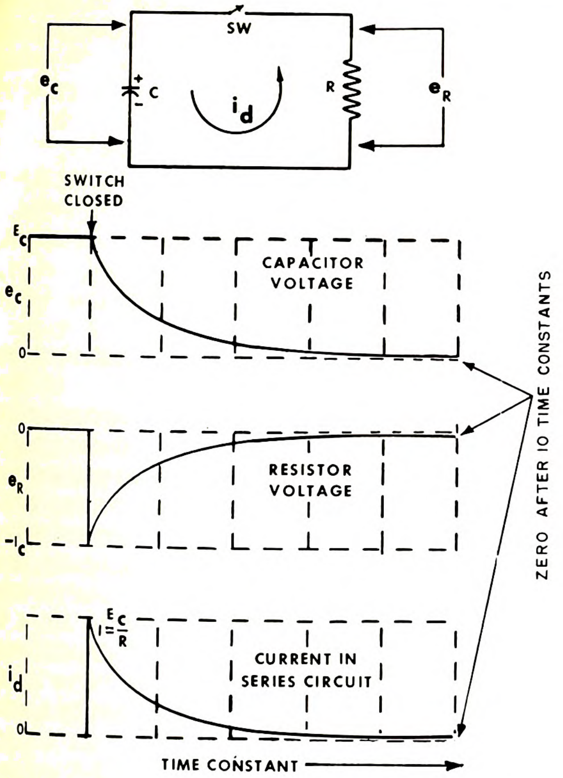

Figure 3-12.—Current and voltage during capacitor discharge.

SOLVING CAPACITOR DISCHARGE PROBLEMS

To determine instantaneous values of current and voltage in RC circuits during capacitor discharge, use the same methods that you used previously in the charging circuit problems. One fact of significance in discharging circuits is that the voltages across the resistor and the capacitor follow the same curve inasmuch as they both start at high values and decrease exponentially to zero. Therefore, curve B of the universal time constant chart represents the instantaneous values of voltage across both the capacitor and the resistor during capacitor discharge. The only requirement is that e_R be assigned a polarity opposite that of e_C. Remember that the voltage across the resistor is not only equal but opposite to that across the capacitor when the capacitor is discharging. This is as it should be according to Kirchhoff's law, which states that the sum of the voltages around a series circuit is zero.

As just mentioned, you can use either method given earlier to solve for the voltage and current values; that is, the curves which roughly approximate voltages and currents, or the universal curves.

Examples:

PROBLEM 1.—Assume that in the circuit of figure 3-13 the capacitor is charged to 200 volts when the switch is closed. Find the capacitor voltage 300 microseconds after the switch is closed.

Solution:

First, find time constant by the equation

$$t.\ c. = RC.$$

Substituting the values indicated in the circuit,

$$t.\ c. = 100K \times 0.001 \mu f.$$

$$t.\ c. = 10^5 \times 10^{-9} = 10^{-4} \text{ seconds}$$

Therefore,

$$t.\ c. = 100 \text{ microseconds.}$$

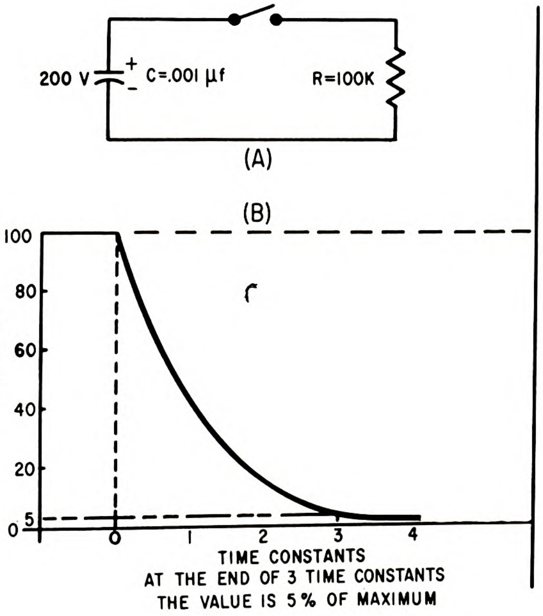

Figure 3-13.—Capacitor discharge problem.

Since the time constant is 100 microseconds and since the problem requires 300 microseconds, the capacitor discharged for 3 time

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constants. Refer to the heavy lined curve shown in (B) of figure 3-9 or (b) of figure 3-13. There you see that at 3 time constants the capacitor has discharged to about 5 percent of E_C or 0.05 x 200, or 10 volts. Thus, after 300 microseconds, the capacitor voltage is 10 volts.

PROBLEM 2.—Find the current 200 microseconds after the switch is closed.

Solution:

The current decreases from an initial value of 2 ma. (calculated by Ohm's law, $\frac{E}{R} = \frac{200V}{100K}$). The time of discharging is 200 microseconds, or 2 time constants. Referring to the universal time constant curve B (fig. 3-10), the value of current at 2 time constants is 14 percent of 2 ma. or 0.28 ma.; the current after 200 μsec. is 0.28 ma.

PROBLEM 3.—Find the resistor voltage after one time constant, using time constant curve B.

Solution:

After 1 time constant, the voltage drops to 37 percent of its maximum value. (A change of about 63%.) Since the resistor voltage starts at 200 volts and drops to zero when the capacitor is completely discharged, it is 37 percent of 200 volts, or 74 volts, 1 time constant after discharge starts. Notice here that curve B, which is the capacitor discharge voltage curve, also is used for voltage decrease across the resistor during discharge.

Effect of Varying R and C

Thus far, the RC curves illustrated were drawn separately, but in figure 3-14 three curves are superimposed on one another fo the purpose of showing what effect changing th time constant (RC) has on the waveshape pro duced by an RC circuit. Each curve represent an RC circuit having the same applied voltag but a different time constant. Naturally, in a RC circuits, values reach maximum (or zer after 10 time constants. However, since th duration of each time constant is differe the curves differ in duration. The curve labele short RC, for example, is produced by a sma

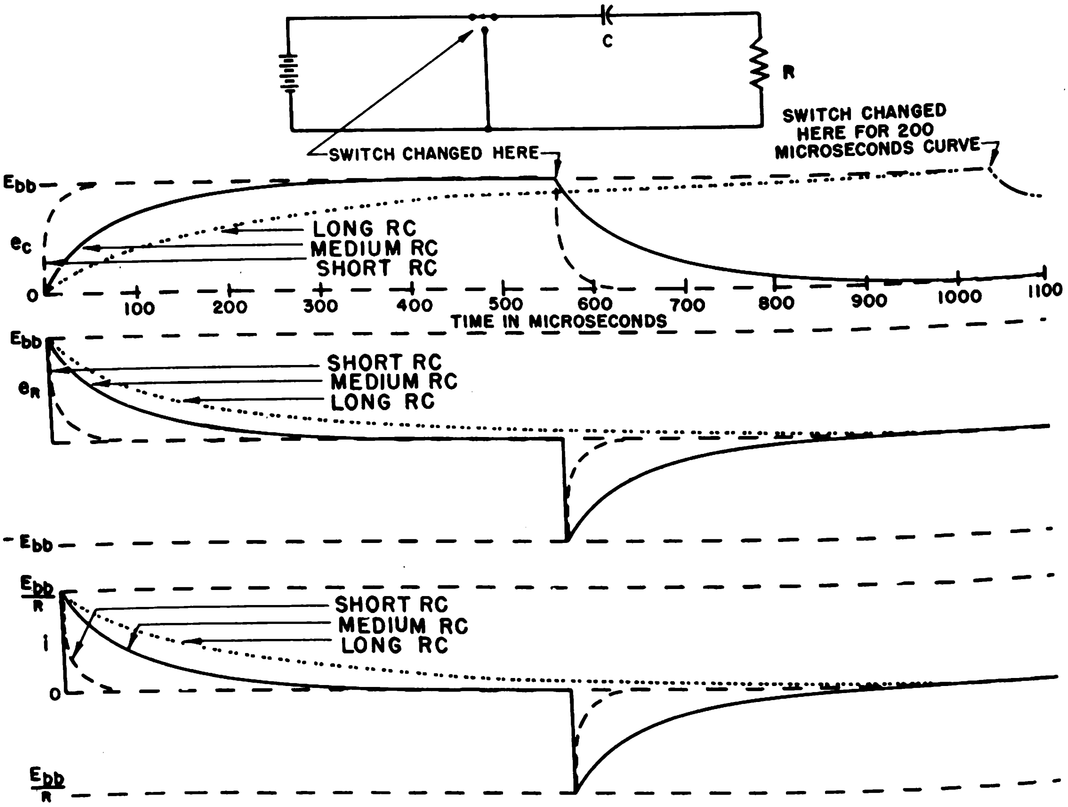

Figure 3-14.—Effect of varying R and C in RC circuit.

RC; that is, a small capacitor and resistor combination. A small capacitor has the property of quick charging, and a small resistor connected to it permits a high charging current to flow, further facilitating rapid charging. Due to the small RC, this curve reaches its maximum limit quickly or in approximately 100 microseconds.

Larger RC values produce longer time constants. A larger capacitor requires more electrons to charge it completely, while a larger resistor limits the current more and thereby increases the time required for charging. Thus, the curve labeled long RC has a longer time constant. Notice that a much longer time is required to fully charge this capacitor.

Notice that the e_R and i curves both follow the capacitor charge curve exactly. The first half of each of these curves represents the capacitor charge, and the last half the capacitor discharge. The difference between the two halves is due to the position of the switch.

LONG AND SHORT RC TIME CONSTANTS

In contrast with the time constants shown in previous illustrations, the time constant used in figure 3-15 is called a MEDIUM TIME CONSTANT. Actually any distinction between long, short, or medium time constants is arbitrary, but in general the practice is to consider that a circuit has a long time constant when the RC product is equal to or greater than ten times the longest portion of the applied voltage, a short time constant when the RC product is equal to or less than one-tenth the shortest portion of the applied voltage, and a medium time constant when the RC product lies between these two limits. However, after ten RC times the charge is over 99.9 percent. For practical purposes the capacitor may be considered to be fully charged at the end of this time. When a capacitor is discharging, the discharge rate is the same as the charge rate; that is, it discharges 63.2 percent of its remaining charge in each RC time constant. After ten RC times the capacitor can be considered to be completely discharged.

The assumption that 10 RC times are necessary for a capacitor to make a 100 percent change of charge will now be explained. That figure is used ONLY because of simplicity in arithmetic. Various schools and textbooks use different figures; for example, some Air Force publications use 5 RC times and some Army publications use 7 RC times. Actually, the exact figure is of little importance in application, but some figure must arbitrarily be chosen in order to teach the theory of RC time so that the student may understand this all-important phase of electronics.

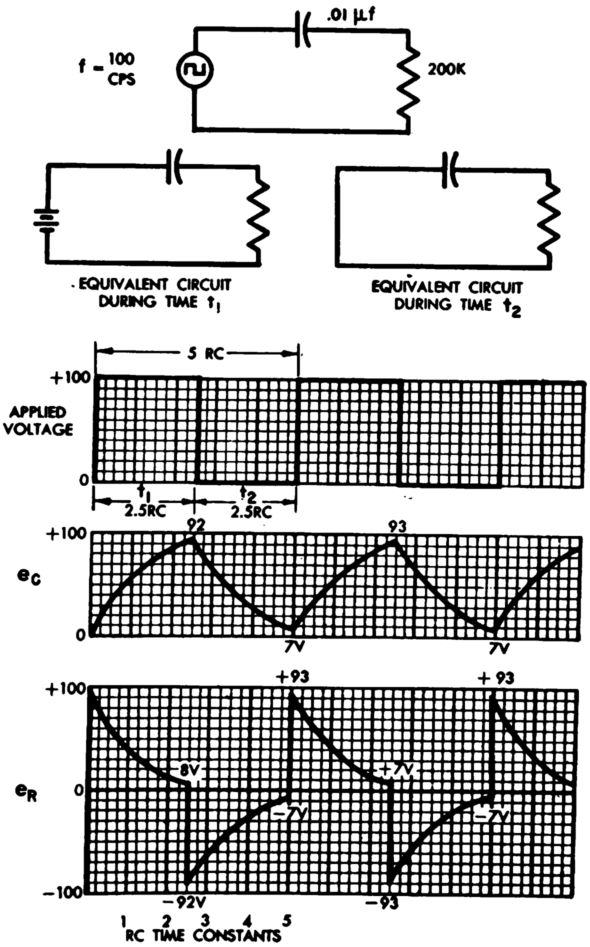

Figure 3-15.—Effect of medium time constant on square-wave input.

Also, schools and textbooks may differ on the definitions of LONG and SHORT time constants. These are also arbitrary figures of little actual importance in electronics design. In this training course (and in the AT "B" school), a LONG time constant is considered to be TEN TIMES THE LONGEST PORTION OF THE APPLIED WAVE; a SHORT time constant is considered to be ONE-TENTH THE SHORTEST PORTION OF THE APPLIED WAVE; and a medium RC time constant is considered to be any time constant that falls between these two figures.

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By this time in your Navy career you are aware that very few things in electronics are perfect—a resistor is not a pure resistance, an inductor is not a pure inductance, capacitors are far from perfect, and most formulas used by technicians are only approximately correct. Electronics is taught as a nearly pure science only because it would be very confusing to delve into the variations, inconsistencies, and exceptions of each subject. Only at the engineer's level is such exacting knowledge of great importance. Therefore, considering the subject under discussion, RC time, the figures used as working points are arbitrary and chosen only for simplicity of instruction.

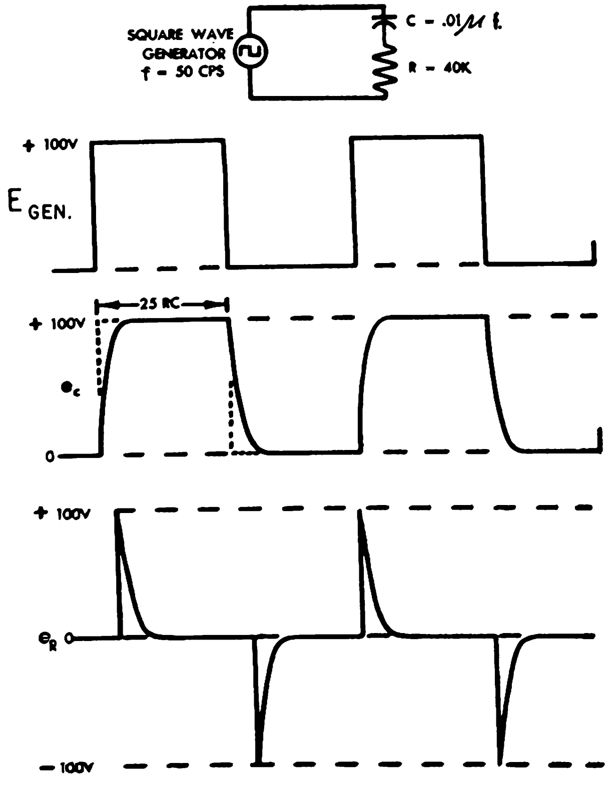

Figure 3-16.—Waveshapes for short time constant RC circuit.

MEDIUM TIME CONSTANT

Since most RC circuits in electronics are associated with high-speed timing devices, the voltages generally applied to an RC circuit are rapidly repeating square-wave voltages rather than d-c voltages. Figure 3-15 shows the capacitor and resistor voltages resul from applying a square wave whose alternat are 2.5 time constants in duration. For purpose of analyzing the circuit, the square- generator is redrawn into two equivalent cuits. They make it easier to understand action of the generator, providing that you gard the square wave first as a constant vo lasting for a definite time, and then as a voltage lasting for an equal time. Since constant voltage appears as a battery durin first half of the square wave, the equiv circuit for this time period (t_1) shows a bat During the second half of the square wav the zero voltage period, the capacitor discl current flows through the generator. therefore not necessary to include the ba in the (time t_2) equivalent circuit. The ba however, must be replaced by whateve sistance the discharge current encounte the generator, which in this case is consi to be zero resistance.

SHORT TIME CONSTANT

If a balanced square wave is applie circuit having a short time constant, the will be as depicted in figure 3-16. (Rem that the length of the portions of the wave is the ONLY thing that determines w an RC circuit's time constant is short o An RC combination will have a shor constant to all pulses of a certain durat longer, and a long time constant to all of a certain duration and shorter.) The of figure 3-16 has a time constant of second, or 400 μseconds. The applied w 50 c.p.s. balanced square wave. The dur 1/2 of the square wave is 1/100 of a or 10,000 μ seconds. The applied w therefore, considerably longer in durati ten times the circuit's time constant o seconds; or, the circuit's time cons considerably less than 1/10 of the short tion of the applied wave. In a balanced wave both portions are the same length RC circuit exhibits the same time co both halves. Each portion of the squa in the figure is 25 times as long as constant of the circuit. The circuit, th has a short time constant to the 50 c.p applied. If you assume as before square wave is a d-c voltage applied fo and then shorted out, you can apply t you used previously. These rules state charging rate for a capacitor with a short time constant is very high at first and then decreases to zero as the capacitor reaches full charge. Similarly, its discharge RATE is very high to start with and then gradually decreases to zero. The early rise of the capacitor voltage to the full applied voltage and its quick drop to zero cause the capacitor waveshape to resemble the square wave input. On the resistor the short duration of the high charging and discharging currents have a quite different effect. The rapid rise and drop of the circuit current causes the resistor waveshape voltage to be peaked at each square wave variation (change from maximum voltage to zero or from zero to maximum). These sharp peaks are excellent for initiating action in another circuit, as, for example, in a radar transmitter which is designed to transmit a pulse whenever it is triggered by a positive voltage. The sharp positive pulses shown in the illustration may be used for this purpose since they occur at precisely the changeover time in the square wave.

LONG TIME CONSTANT

Figure 3-17 shows the waveshapes produced by an RC with a long time constant; the time constant is ten times as long as the longest portion of the wave.

On referring to the universal curve, you will see that the capacitor in the circuit will charge almost linearly for about one-tenth of a time constant. This causes the capacitor curve in the case illustrated to be linear during the entire half cycle. The dotted curve shows how the capacitor would have continued to charge if the applied voltage had not been removed. Note how the voltages in the circuit illustrated comply with Kirchhoff's law which states that the sum of the voltage-drops around the circuit must equal to the applied voltage. During the first half cycle, the applied voltage is 100 volts. Although the resistor and capacitor voltages are constantly changing their sum at any one instant is also 100 volts. Thus, at the end of the first half cycle, for example, the capacitor voltage is 10 volts, and the resistor voltage is 90 volts, making a total of 100 volts and fulfilling Kirchhoff's law. During the other half cycle, the applied voltage from the generator is zero. In this case the only voltage in the circuit is the capacitor voltage, which starts out at 10 volts and discharges 10 percent. As a result, the resistor voltage becomes minus 10 volts making all voltages around the circuit equal to zero and again fulfilling Kirchhoff's law.

In the curves of figure 3-17, notice that the capacitor is permitted to charge to only 10 percent of the applied voltage each time the generator pulses. It also discharges only 10 percent of its charge each time the generator voltage becomes zero. Ten percent of 100 volts is 10 volts, so on the first half-cycle the capacitor charges to 10 volts. During the next half cycle the capacitor discharges 10 percent of 10 volts, or 1 volt. When the second pulse is applied the capacitor still has 9 volts of charge, so the effective voltage applied is only 91 volts. Ten percent of 91 volts is 9.1 volts, so that is the amount of voltage charge added to the capacitor during the second pulse from the generator. With each cycle, the capacitor adds 10 percent of the effective voltage, and discharges 10 percent of its charge. It follows that the capacitor will gradually build up a d-c component around which the applied waveshape will vary. The figure shows that the d-c component will eventually settle at 50 volts, and the capacitor voltage will vary above and below this d-c voltage.

The resistor voltage must at all instances be the difference between the capacitor voltage and the generator voltage. Since a capacitor cannot change its charge instantaneously, the resistor voltage must at the first instant be equal to the generator voltage. Then as the capacitor begins to charge, the resistor voltage decreases at the same rate. At the end of the first pulse, the capacitor has 10 volts of charge and begins its 1 volt discharge through the resistor. Since resistor current has reversed, its voltage polarity must also reverse. The positive 10 volts on the capacitor is the total voltage in the circuit, so the resistor voltage must go to negative 10 volts to satisfy Kirchhoff's Law. Thereafter, the capacitor and resistor voltages are equal and opposite until the second pulse is applied.

Since the capacitor gradually assumes a d-c component of charge around which the applied voltage varies, it follows that the resistor voltage must also assume a new point around which to vary. The figure shows that the resistor voltage, which at first varied around 50 volts, moves down to vary around zero volts. This is the correct operating level for the resistor in a circuit with a long time constant. As the capacitor voltage (dotted lines, final curve) varies from positive 55 volts to positive 45 volts, the resistor

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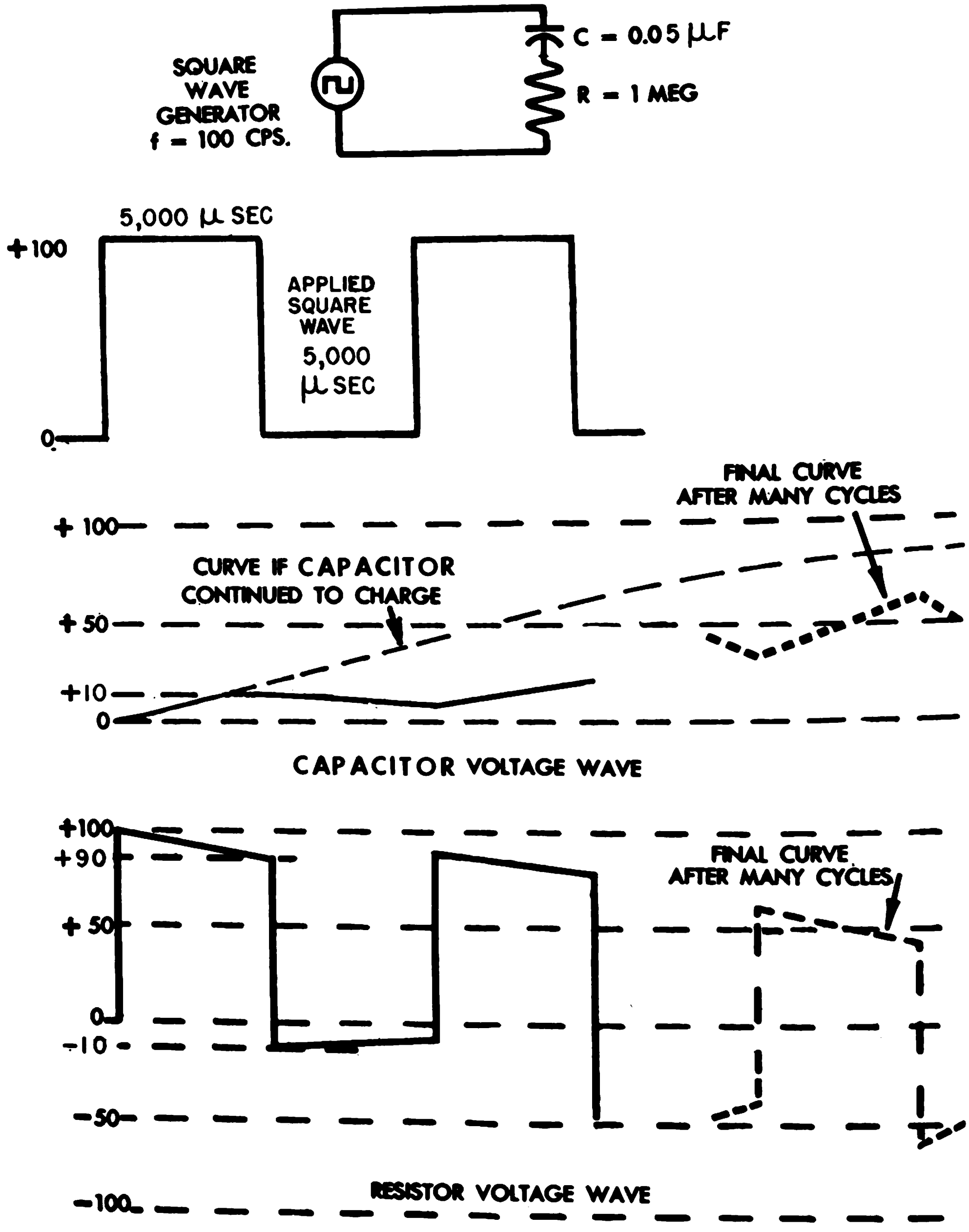

Figure 3-17.—Waveshapes for long time constant RC circuit.

voltage varies above and below zero by the proper amount to equal a total of 100 volts with the capacitor voltage. Note that each time the pulse is applied or removed, the resistor takes the entire 100 volts change at the first instant.

Differentiation and Integration

An RC voltage divider that is designed to distort the input voltage waveshape is known as a differentiator or integrator, dependi
locations of the output taps. The outpu
differentiator is taken across the r
while the output from an integrator
across the capacitor. Such circuits wi
the shape of any complex alternatin
waveshape that is impressed on them
distortion is a function of the value o
constant of the circuit as compared to
of the waveshape. Neither a differen
an integrator can change the shape

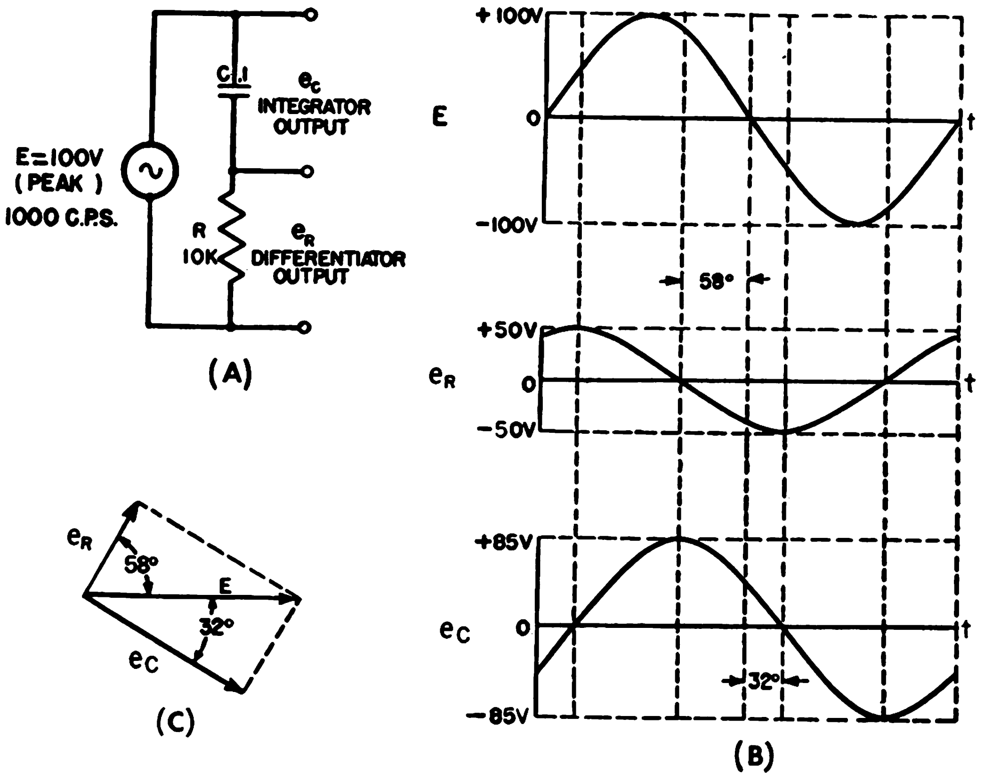

Figure 3-18.—RC differentiator and integrator action on a sine voltage.

sine wave. Both integrator and differentiator outputs are shown in figures 3-18, 3-19, and 3-21, but usually only one output from each circuit is used in practical circuits.

SINE-WAVE INPUT

If a 1,000-cycle sine-wave voltage that has a peak value of 100 volts is applied to an RC voltage divider with an intermediate or short time constant, the sine wave will be shifted in phase. Figure 3-18 illustrates the case in which an intermediate R-C circuit is employed.

R is 10,000 ohms and C is 0.1 microfarad, so that the time constant of the circuit is R x C or 1,000 microseconds. The duration of 1 cycle of the 1,000 cycle voltage is $\frac{1}{1,000}$ seconds, or 1,000 microseconds. The time constant of the circuit is medium to the applied signal and the output will be distorted in phase and reduced in amplitude.

A-c voltage divider equations apply to this circuit; and the peak voltage across the resistor is found to be 50 volts, and across the capacitor 85 volts. Since these are vector quantities, they must be added vectorially to obtain the 100-volt input that Kirchhoff's laws require (fig. 3-18(C)). This means that phase differences between the input, the differentiator output, and the integrator output will exist. Both outputs are sine waves as illustrated in (B). In the case shown, the differentiator output e_R is a sine wave which leads the input voltage by about 58 degrees, while the integrator output e_C is a sine wave which lags the input voltage by about 32 degrees. It may be shown, however, that the sum of the two outputs at every instant equals the instantaneous input voltage.

SQUARE-WAVE INPUT

If the same circuit (fig. 3-18) has impressed on it a 1,000-cycle square-wave voltage instead of a sine wave, the outputs shown in figure 3-19 (B) are obtained.

The square-wave voltage of 200 volts peak-to-peak is placed across the input of the circuit and the capacitor alternately charges positively and negatively by an amount determined by the

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RC time constant. Since in this case the time constant of the circuit is medium to the square wave, the capacitor never fully charges during either half cycle and as a result the integrator output has a smaller amplitude than the input. Figure 3-19 (B) illustrates the outputs of the voltage divider. The two outputs must add at all times to the input voltage; consequently the differentiator output must be as shown. This output has a maximum amplitude that is greater than the input amplitude since the voltage left on the capacitor from the previous half cycle will add with the input voltage. The sum of these two voltages will appear as a voltage drop across the resistor at the instant the polarity of the input voltage changes.

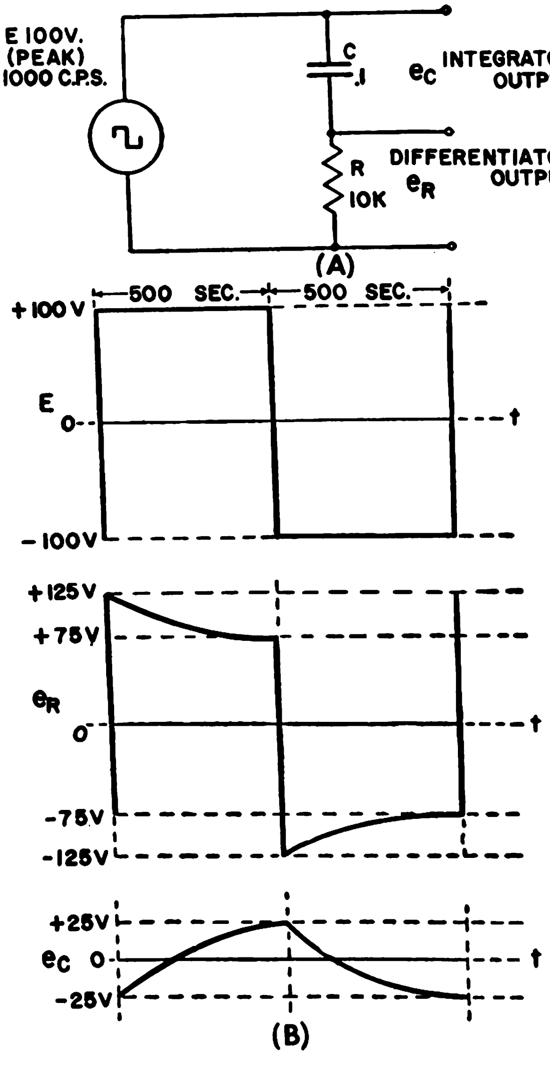


Figure 3-19.—RC differentiator and integrator action on a square wave.

Figure 3-20 shows the effect of differe
values of time constant on the output of t
voltage divider. Figure 3-20 (A) has a ti
constant equal to one-tenth the time of t
input wave. The capacitor has time to beco
fully charged during a half cycle for all pra
tical purposes. Such a circuit when used as
differentiator is often known as a PEAKER. T
figure also makes apparent the fact that t
peaks produced have an amplitude exactly tw
the input amplitude due to capacitor and in
voltage addition.

Figure 3-20 (B) shows the effect of a ti
constant that is 10 times as long as the pul
The differentiator output is almost the same
the input, and the integrator output has a v
low amplitude, but for all practical purposes
linear. It is noticeable that the integrator out
is a back-to-back sawtooth of very low amp
tude. After amplification this sawtooth i
valuable part of some waveshapes used in el
tronics.

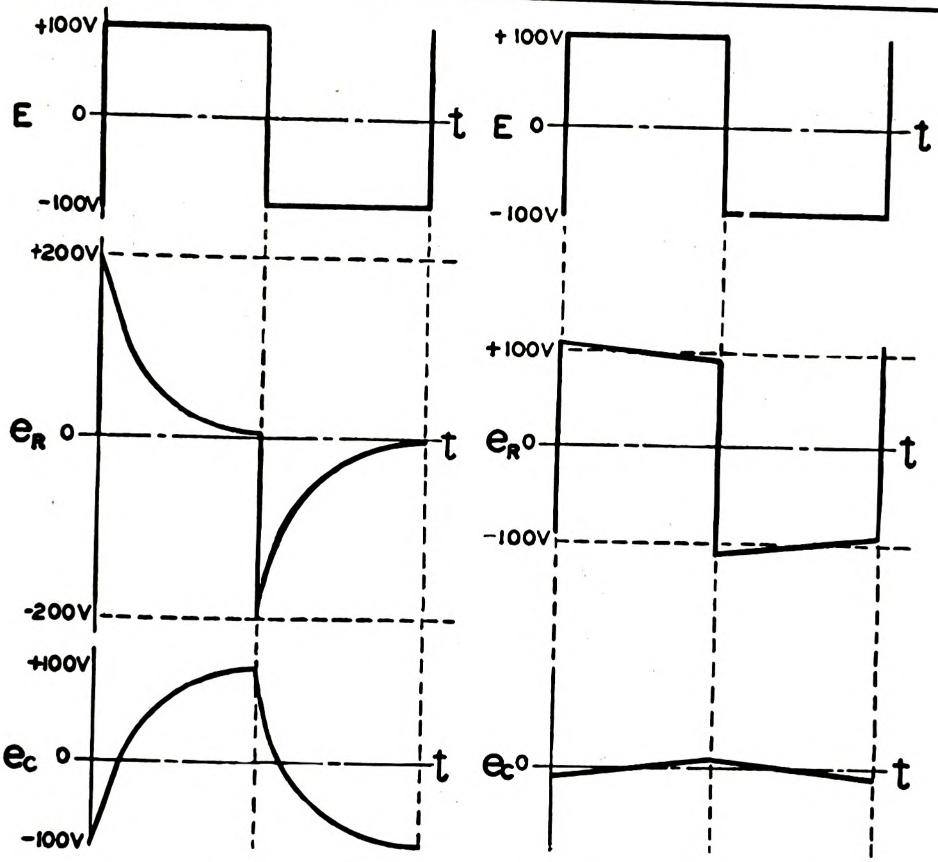
SAWTOOTH-WAVE INPUT

If a back-to-back sawtooth voltage is app
to an RC circuit with a time constant one-t
of the rise (or fall) time of the input voltage,
result is as shown in figure 3-21. Note that
sawtooth, unlike a square-wave voltage, doe
make instantaneous changes. The voltage ch
of a sawtooth takes place over a length of
and the capacitor voltage e_C will follow th
put voltage very closely if the time con
of the circuit is short. The shorter the
constant, the closer it will follow. The r
is that the integrator output very closel
sembles the input. The amplitude will be sli
reduced and there will be a slight phase

Since the voltage across the capacitor i
creasing at a constant rate, the charging
discharging current will be constant. A con
or steady, current flow means the output vo
of the differentiator will be constant during
half of the sawtooth input. The resulting s
wave is shown in figure 3-21(B). It can be
that the integrator output adds to the differe
tor output at every instant to equal th
stantaneous input voltage.

MISCELLANEOUS INPUTS

Various voltage waveforms other than
represented above may be applied to sh



(A) RC=.1 PULSE TIME OF E

(B) RC=10X PULSE TIME OF E

Figure 3-20.—Effect of time constant on RC differentiators and integrators.

circuits for the purpose of producing, across the resistor, an output voltage with an amplitude proportional to the RATE OF CHANGE of the input. The shorter the RC time constant is made with respect to the period of the input wave, the more nearly the voltage across the capacitor conforms to the input. Thus the differentiator output becomes of particular importance in very short RC circuits.

The differentiator outputs for various types of input waves are shown in figure 3-22. In (A) the slope of the trailing edge of the sawtooth voltage is greater than that of the leading edge; therefore, the amplitude of the output voltage e_R is greater during this portion of the cycle. This same relationship of amplitude of the output voltage e_R and the steepness of the input voltage rise or decay is illustrated in both (B) and (C).

TRANSIENT VOLTAGES IN L/R CIRCUITS

The operation of L/R circuits is similar to that of the RC circuits just discussed since the inductor current in an inductor-resistor circuit rises exactly like capacitor voltage in an RC circuit. With slight modifications, all the waveshapes obtainable in an RC circuit are also obtainable in an L/R circuit.

L/R Charging Circuits

Figure 3-23 shows typical current and voltage curves produced in L/R circuits. In the L/R circuit shown, inductance L is assumed to be perfect; that is, it offers no resistance to d.c. When the switch is open, there is no voltage

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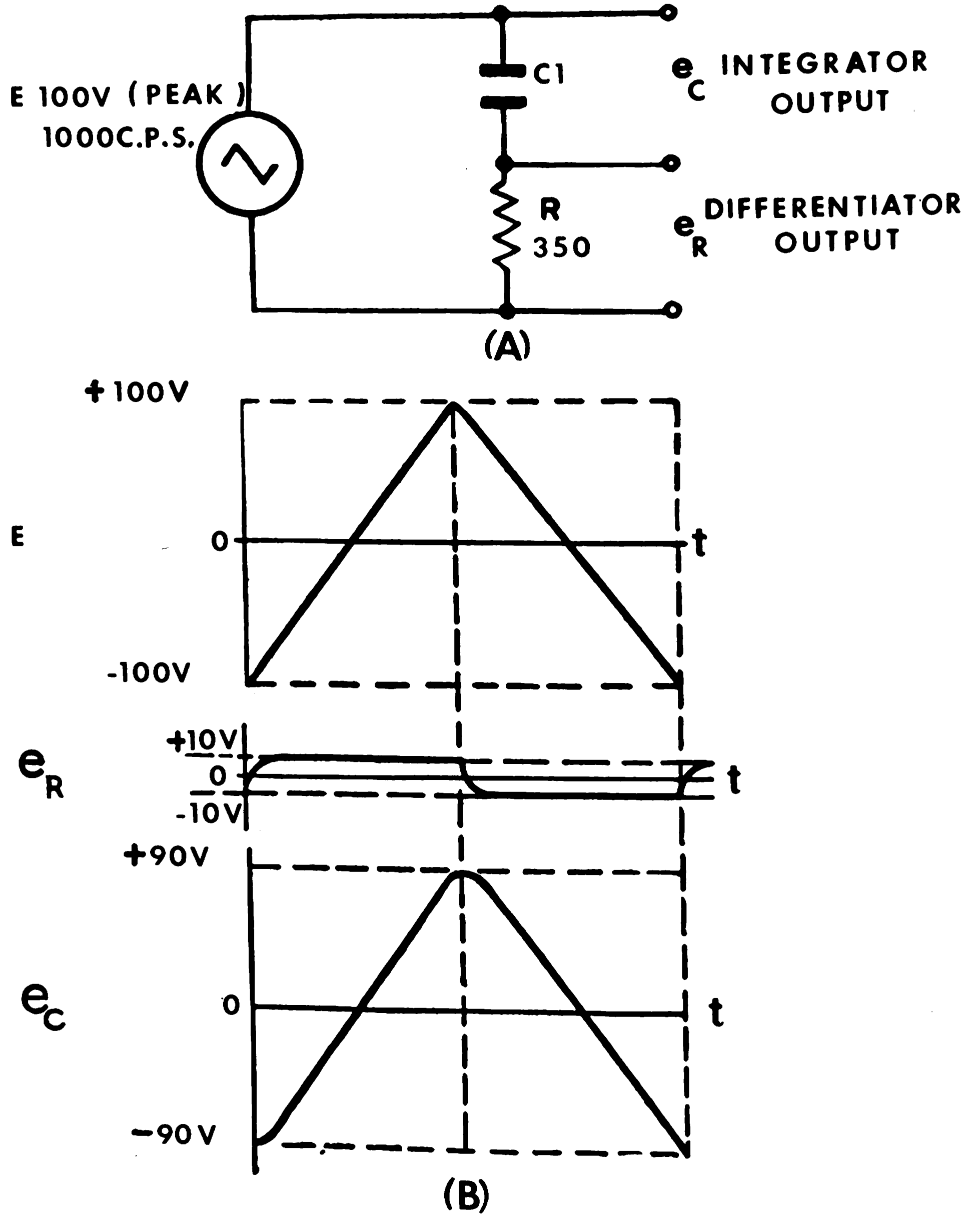

Figure 3-21.—RC differentiator and integrator action on a sawtooth wave.

across the circuit, and because of this the current and voltage are zero. When you close the switch, the battery voltage E_{bb} is applied across the resistor R and inductance L. Current attempts to flow, but the inductor opposes this current by building up a back e.m.f., that, at the initial instant, exactly equals the input voltage E_{bb}. Since current cannot flow under this condition, there is no voltage across the resistor R. The two lower curves thus show that at the instant the switch is closed circuit, all the voltage is impressed L and no voltage across R.

As current starts to flow, the voltage pears across R, and the voltage e_L acros reduced by the amount of e_R at that ins reduced voltage across the inductor m less rapid increase in i_L and thus a less increase in the resistor voltage. The e_L shows that e_L finally becomes zero wh

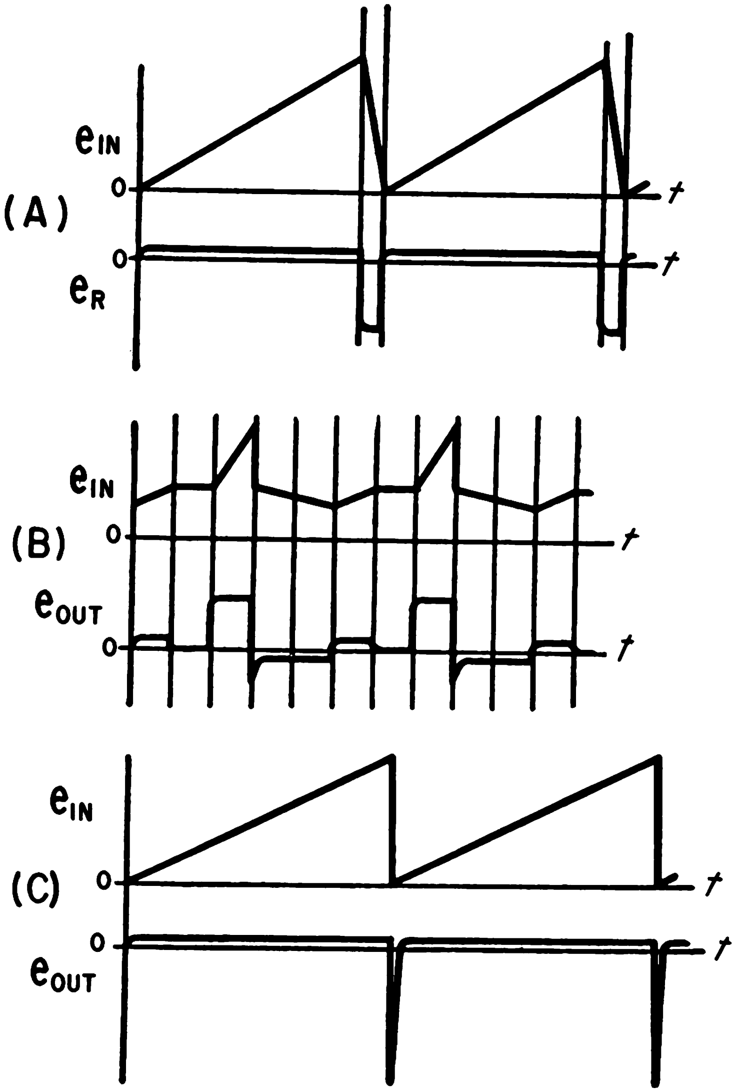

Figure 3-22.—Differentiator outputs of short RC circuits for various input voltage waveshapes.

current stops increasing while the e_R builds up gradually to the input voltage as the charging current rises. Under a steady state condition, the resistor is the only factor which limits the magnitude of the current.

Suppose you examine the three curves closely. Notice in the i_L (instantaneous current) curve that the current starts from zero and increases rapidly at first and then tapers off to practically a zero rate of increase at the end of 10 time constants. According to Ohm's law, the instantaneous values of the voltage across the resistor are directly proportional to the current flowing through it. Therefore, the e_R curve is similar to the i_L curve.

Since the sum of voltage around a series circuit (the circuit illustrated is a series L/R circuit) equals zero, and since the applied voltage is constant, the inductor voltage e_L is always equal to the difference between E_{bb} and e_R. The inductor voltage equals E_{bb} when the resistor e_R equals zero, and equals zero when e_R is at maximum value. If you reverse the polarity of the e_L curve, you may also consider it is representing the back e.m.f. in the inductor. (The polarity of back e.m.f. is always

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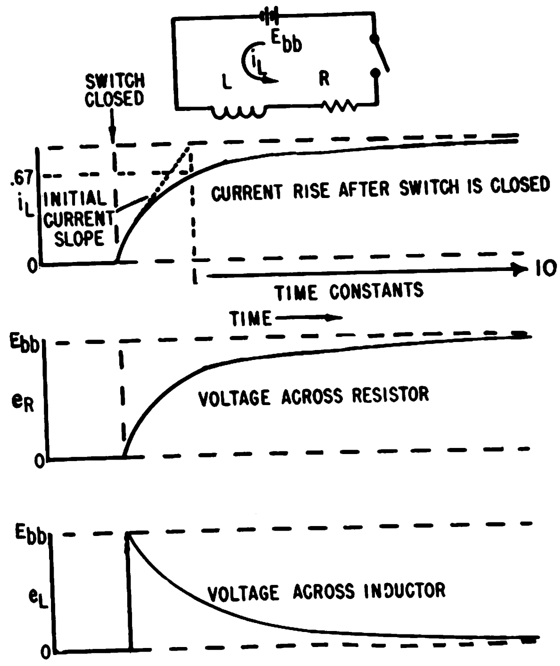

Figure 3-23.—Current and voltage curves in L/R charging circuit.

opposite that of the applied voltage.) At first, the back e.m.f. is high since the current tends to jump to a value of $\frac{E_{bb}}{R}$. This large back e.m.f. opposes the applied voltage and keeps the current small. In order for the back e.m.f. to be sustained at its initial high value, the current must continue to increase at the initial rate (dotted line in i_L curve). This is not possible, however, for as the current increases, the resistor voltage increases proportionately. The increase in resistor voltage effectively reduces the inductor voltage. Hence, the back e.m.f. decreases while current and resistor voltage increase. All three curves change along exponential curves.

L/R Time Constant

The meaning of the time constant in an L/R circuit is similar to the meaning of the time constant in an RC circuit. An L/R time constant is defined as the time required for the current through an inductor to increase to 63.2 percent of its maximum value. The formula for the L/R time constant is

$$\text{t.c.} = \frac{L}{R}$$

where t.c. represents the time constant in se onds, L the inductance in henrys, and R the r sistance in ohms.

The ratio $\frac{L}{R}$ also represents the time r quired for the resistor voltage to equal 6 percent of the applied voltage, and the time r quired for the inductor voltage to equal 3 percent of the applied voltage.

L/R Charging Problems

The shapes of the curves for current voltage in the L/R circuits are like those in RC circuit. Therefore, you can use the rc approximation curves and the universal t constant curves for determining instantane values of current and voltage.

Study the following sample problems to le how to find instantaneous values of current voltage in L/R circuits. These problems solved by the curve chart method.

Examples:

PROBLEM 1.—Using the values indicat the circuit of figure 3-24 find the amou current 200 microseconds after the swit closed.

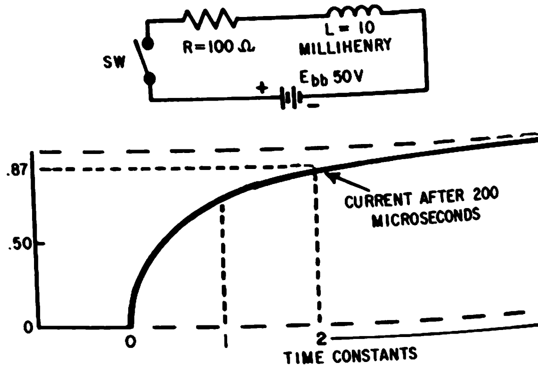

Figure 3-24.—Solving L/R problems

Solution:

Find the time constant by the fo

$$\text{t.c.} = \frac{L}{R}$$

$$\text{t.c.} = \frac{0.01 \text{ henry}}{100 \text{ ohms}}$$

$$\text{t.c.} = 10^{-2} \times 10^{-2}$$

$$\text{t.c.} = 10^{-4}$$

$$\text{t.c.} = 100 \text{ microseconds.}$$

Since the time constant is 100 microseconds, and the time involved is 200 microseconds, the charging action will last 2 time constants. From the rough approximation curves in figure 3-9 or the universal time constant chart in figure 3-10, you find that the current in the inductor is 87 percent of maximum at 2 time constants. Calculating the maximum current by the formula

$$I = \frac{E_r}{R}$$

$$I = \frac{50}{100} = 0.5 \text{ amperes.}$$

Since the maximum current is 0.5 amperes, it will be 0.87 of 0.5 or 0.435 amperes at the end of 200 microseconds.

PROBLEM 2.—Using the same circuit repeated in figure 3-25 and the same time constant find e_R and e_L 50 microseconds after the switch is closed.

Solution:

The rough approximation curves do not contain a 50 microsecond time. Therefore, refer to the universal time constant chart. (Curve A is the resistor voltage curve; curve B the inductor voltage during charge.) From curves A and B,

$$e_R = 0.4 \text{ of maximum voltage}$$
$$e_L = 0.6 \text{ of maximum voltage}$$

Therefore,

$$e_R = 0.4 \times 50 \text{ volts} = 20 \text{ volts}$$
$$e_L = 0.6 \times 50 \text{ volts} = 30 \text{ volts}$$

L/R Discharging Problems

The curves shown in figure 3-26 are formed when the source of energy is removed from a series L/R circuit, and the energy stored in the magnetic field is returned to the circuit by the collapse of the field. At the initial instant when you open the switch, the resistor voltage e_R attempts to decrease to zero, but the inductance of the inductor resists any change in current and tends to maintain the current flow. This action of the inductor occurs because opening the switch

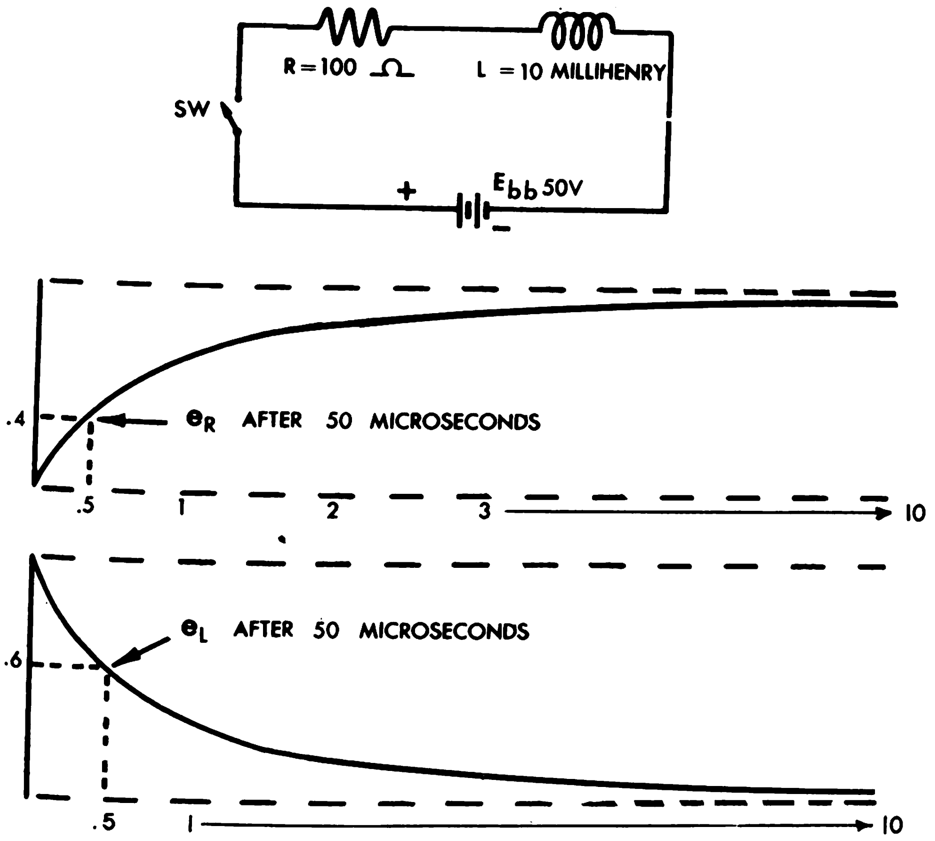

Figure 3-25.—Solving L/R problems.

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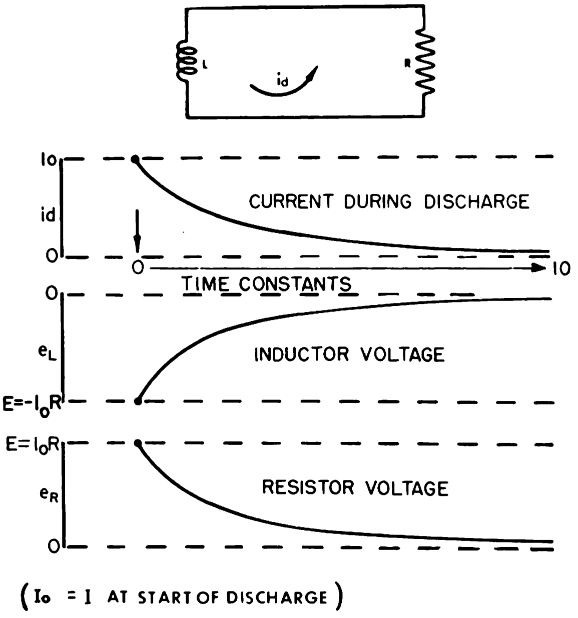

Figure 3-26.—Voltage and current curves during collapse of inductor field.

removes the applied voltage, causes the current flow in the circuit to tend to cease, and starts the collapse of the magnetic field about the inductor.

This collapse induces a voltage in the induc
which causes the current to flow in the same
rection that it did when the circuit was char
Now the self-induced voltage of the coil is
source voltage in the circuit and its polari
opposite to what it was while charging. As
discharge current i_d begins to decrease,
voltage across R decreases proportiona

Since $e_r + e_L = 0$, as previously menti
in L/R charging, the value of e_L also decrea
This change continues as shown in the ep
e_L curves until the e_R and e_L voltages are
zero and no current is flowing. The disch
current at the end of one time constant is
percent of maximum.

Study the following sample problems to l
how to find the instantaneous values of cu
and voltage in L/R discharging circuits.
methods employed are like those used
viously in RC discharge circuits. The for
for the L/R time constant previously discu
applies here too.

Solving by use of curves.

PROBLEM 1.—Find the current 150 mi
seconds after the current has started to decr
in the circuit of figure 3-27.

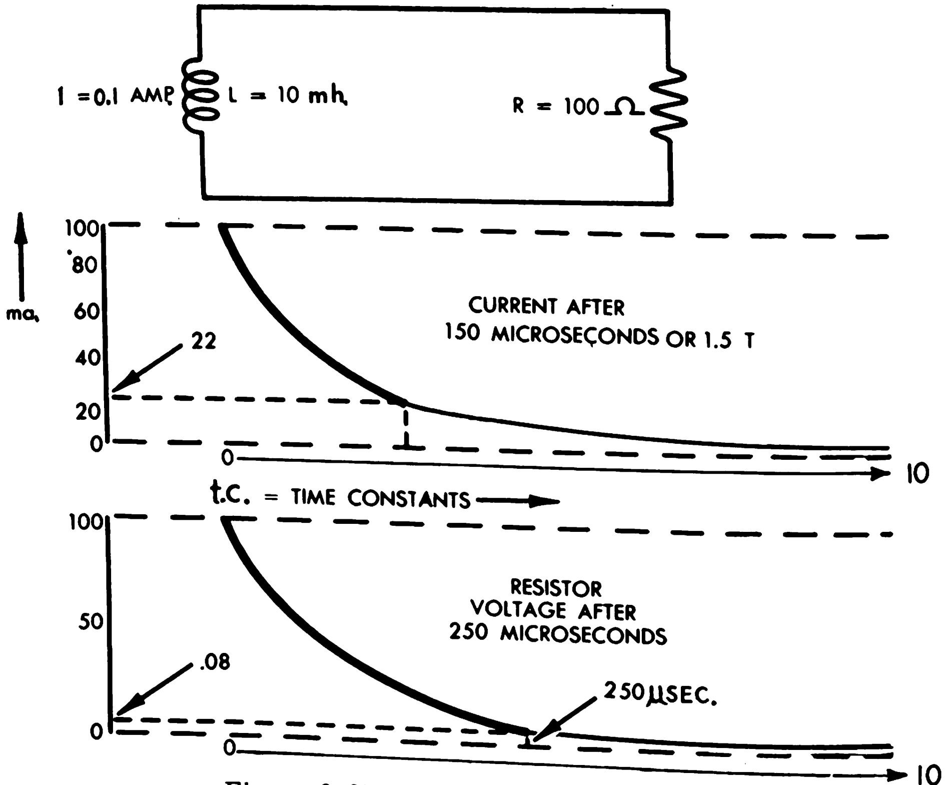

Figure 3-27.—Solving L/R problems.

Solution:
Finding the circuit time constant,

$$\text{t.c.} = \frac{L}{R} = \frac{0.01}{100} = 1 \times 10^{-4} = 100 \text{ microseconds.}$$

Since the time involved is 150 microseconds, the number of time constants involved is 1.5. Then, since the current starts high and decreases to zero (refer to curve B in the universal time constant chart), this curve shows that the current drops to 22 percent of its initial value after 1.5 time constants. The initial current is 100 ma. Therefore, the current after 150 microseconds is equal to 100 x 0.22, or 22 ma.

PROBLEM 2.—Using the same circuit, find the resistor and inductor voltages 250 microseconds after the current starts decreasing.

Solution:
The time given, 250 microseconds, constitutes 2.5 time constants. The universal time constant chart shows that after 2.5 time constants, the voltage drops to 8 percent of its initial value. Therefore, since the maximum voltage of the circuit is 10 volts (E_R = IR = 0.1 a. x 100 ohms), the voltage e_R, after 2.5 time constants, equals 10 x 0.08, or 0.8 volt.

In finding the inductor voltage, utilize the fact that the inductor voltage is the source voltage in an L/R DISCHARGING circuit and, at all time, is equal to the voltage across the resistor. Therefore, since the resistor voltage, e_R, is 0.8 volt after 2.5 time constants, the inductor voltage, e_L, equals 0.8 volt.

Effect of Varying R and L

As shown in figure 3-28, varying the size of R and L in an L/R circuit changes the charge and discharge curves. The changes result from the fact that any change of either R or L changes the L/R time constant. The solid-line curves represent the instantaneous values of current and voltage during charge and discharge when the time constant is medium.

Decreasing the time constant sharpens the slope of both the charge and discharge curves.

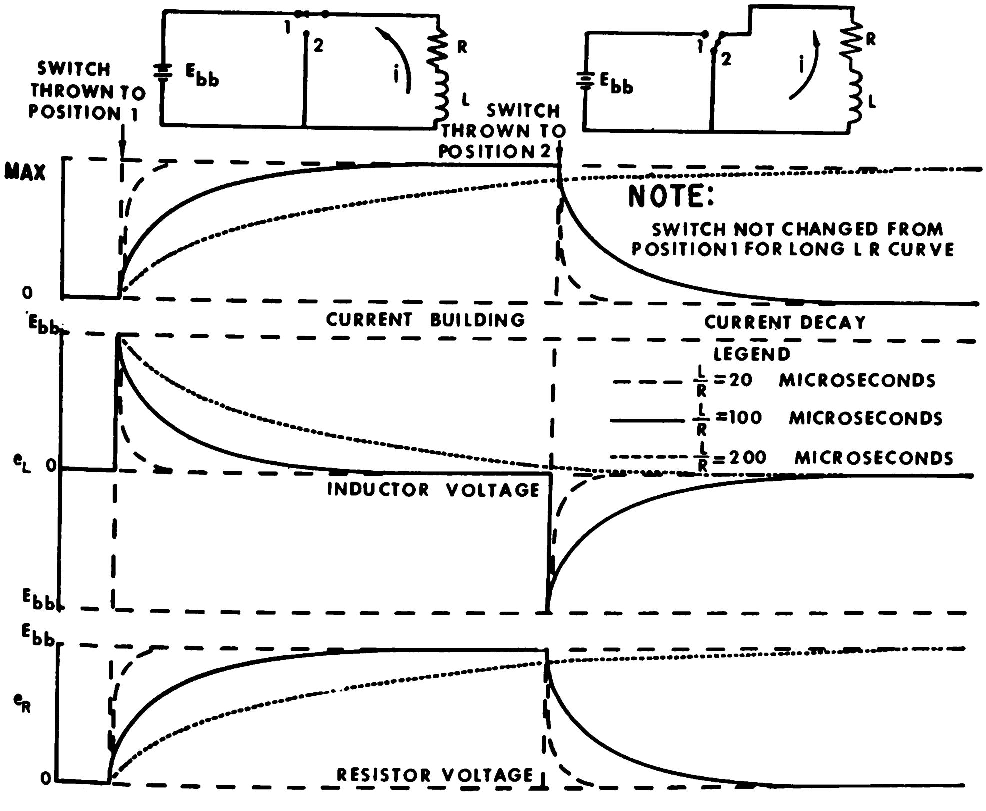

Figure 3-28.—Effect of varying R and L.

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Notice, for example, the dashed-line curve. It represents the effect of reducing the time constant in the circuit to 20 microseconds. A time constant may be reduced either by decreasing L or by increasing R. Decreasing L decreases the opposition to current flow change and permits current to build up and decay more quickly. Increasing R does not affect the inductance, but it does reduce the maximum current flow. Since the maximum value is lower, the current reaches its maximum value more quickly. Because the current builds up very rapidly in a circuit with a short time constant, the voltage across the resistor (e_R), which keeps in step with the current, similarly builds up rapidly. The inductor voltage (e_L), which drops just as fast as the resistor voltage increases, likewise forms a sharp peak. When current is decaying, the resistor voltage and the inductor voltage similarly decay much more rapidly than in a circuit with a longer time constant.

Increasing a time constant produces curves with gradual slopes. For example, notice the dotted-line curve. It represents the curve formed by a long time constant. The rise of current is slower than before because the inductor furnishes more opposition to the flow of current. The effect is noticeable also in the other long time constant curves, where the fall of voltage across the inductor is very slow, and the rise of voltage across the resistor requires appreciably more time than with a medium time constant. Similarly, the decay of current takes longer since a large inductor stores more energy than a small one, and consumes more time in dissipating it through the resistor. If the time constant were lengthened by decreasing R, the same relationships would hold true, because the smaller resistor would dissipate the energy stored in the inductor more slowly. You can see why by analyzing the basic concepts; energy dissipated is power, and power is I^2R. Therefore, if the current (I) is constant and the resistance (R) is decreased, the power dissipation is less at any single instant. This means that if the rate of dissipation is decreased by using a smaller resistor, a longer time is required to dissipate the energy stored in the inductor.

LONG L/R TIME CONSTANT

The waveshapes illustrated in figure 3-29 are those produced when a square wave is applied to an L/R circuit with a long time constant. One important fact to observe here, other than the waveshapes, is how the inductor voltages change polarities during the time that the inductor acts as the source of voltage in the circuit. During current buildup, the end of th inductor that current enters may be called th negative end, for during this time the inducto acts just like any resistance or, for that matter like any other load. However, when the sourc of voltage is removed, the inductor becomes source, and like a battery, the current leave the negative end and enters the positive en Since current flows in the same direction durin either buildup or decay, the polarity of th inductor voltage actually reverses at each ha cycle.

SHORT L/R TIME CONSTANT

The waveshapes illustrated in figure 3- are due largely to using a smaller inducto The small inductor allows the current to rea a maximum value very quickly and thus caus the resistor voltage to be nearly a replica the input voltage. Another result is that t inductor voltage is differentiated into a sha peaked wave.

MEDIUM L/R TIME CONSTANT

The waveshapes produced by applyin square wave to a medium L/R time const circuit with the values indicated are show figure 3-31. The time constant employed equal to the time duration of one half cy of the input square wave. Therefore, the c rent reaches 0.63 amperes, or 63 percen its maximum charge value during the first cycle. During the second half cycle, when applied voltage is zero and the inductor nishes the current, the current drops to amperes or 37 percent of 0.63 amperes. S the applied voltage varies between 0 and volts, there exists a 50-volt d-c compone the waveshape. This d-c component cause current during charge and discharge to about an average value of 0.5 ampere-(50 divided by 100 ohms). However, because c inductance in the circuit, the current doe reach this average value immediately bu proaches it gradually. It does this by sta each current half cycle a little higher. Fo ample, the average value in the second cycle is 0.43 amperes; the current ran 0.63 amperes to 0.23 amperes. In the

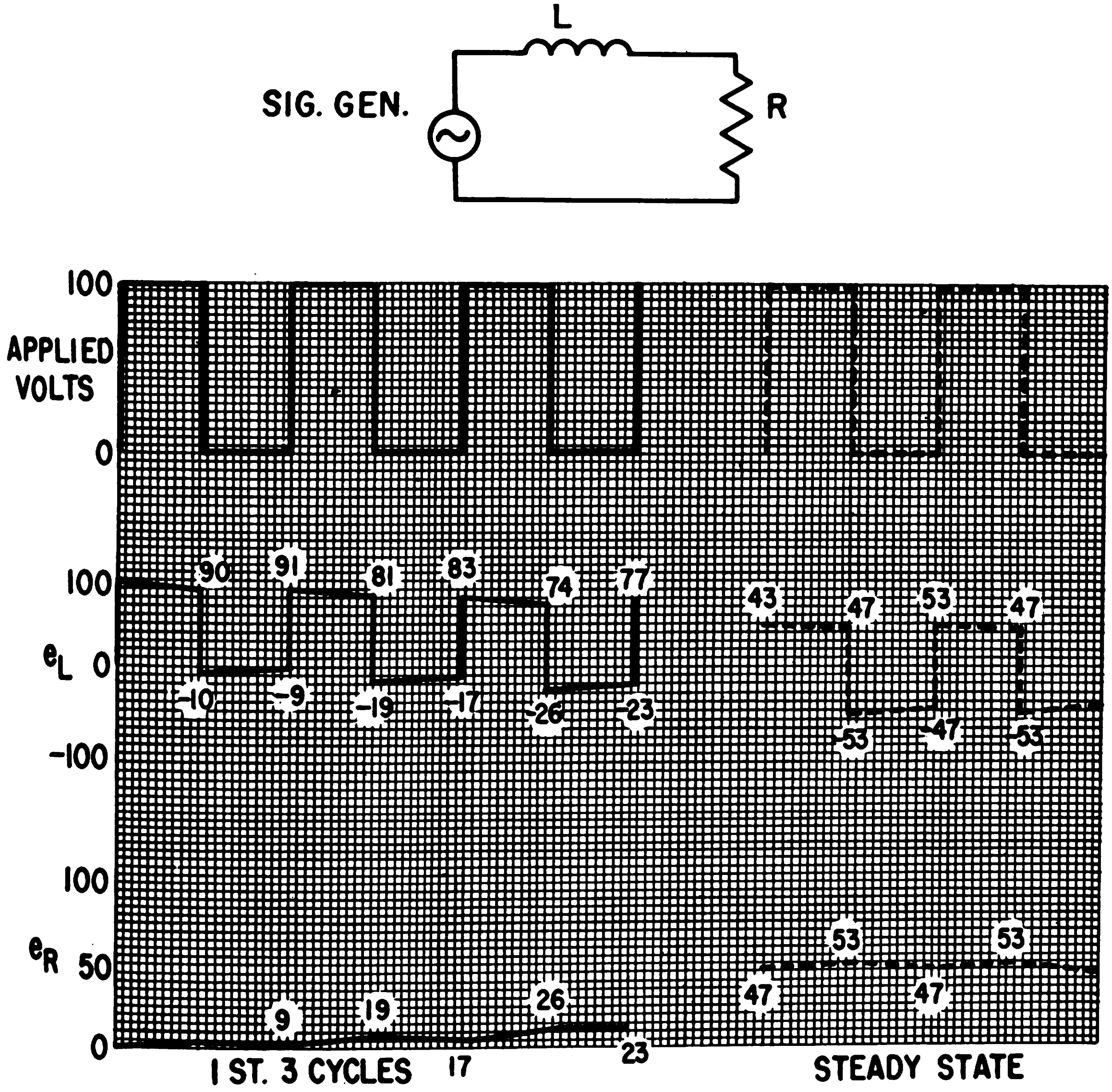

Figure 3-29.—Effect of long L/R time constant.

half cycle it is 0.47, the range being 0.23 to 0.71, and in the fourth, the average is about 0.49 with a range of 0.71 to 0.26 amperes. The current continues its exponential increase of average value and settles at the point where it varies around 0.5 ampere.

With succeeding cycles of the input voltage, the inductor voltage waveform works down until it centers around the zero voltage line; that is, about as much of the inductor voltage is above zero as is below. The e_R voltage wave increases in value with each half cycle of the applied voltage, thus indicating that a d-c voltage component exists in the square wave.

Frequently, the applied voltage does not contain a d-c component at all, but is a pure square wave. In that case waves like those shown in figure 3-32 are produced. The current and voltage waves produced when the pure square wave is applied at the L/R circuit shown are identical to those produced when the square wave has a d-c component, but the resistor voltages are 50 volts less than their original value.

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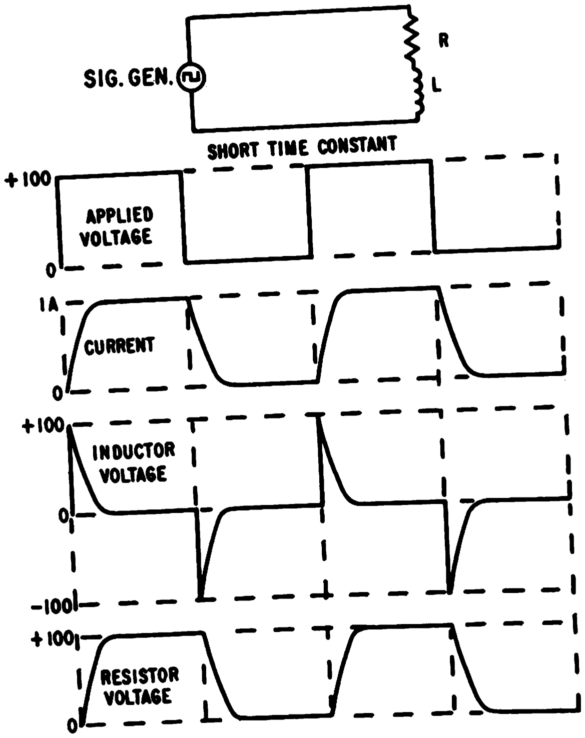

Figure 3-30.—Effect of short L/R time constant.

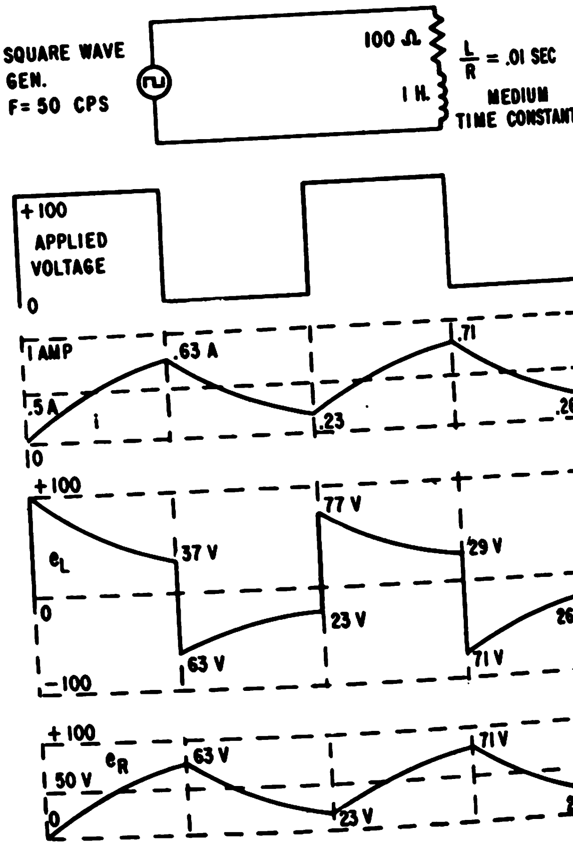

Figure 3-31.—Effect of medium L/R ti constant.

Values of Current and Voltage

An easy means of determining the voltage or current any time a square wave is applied to an L/R circuit is to reduce the circuit to a simple d-c circuit. For example, the L/R circuit in figure 3-33 can be represented by two equivalent circuits—one (t_1) representing the 0.01 second of the square wave when 100 volts is applied, and the other (t_2) the 0.01 second when zero voltage is applied.

During t_1 the circuit may be reduced to an L/R circuit in which the generator is replaced by a battery with a voltage equal to the generator voltage. This is proper since the current rises from zero when a battery is used, just as it does when the square wave voltage is applied. Therefore, if you know the time the voltage is applied and the values of L and R, you can compute the value of current at any time.

During time t_2 you can reduce the L/R circuits shown to a circuit containing a resistor and an inductor in which current is flowing. The inductor is now the voltage source.

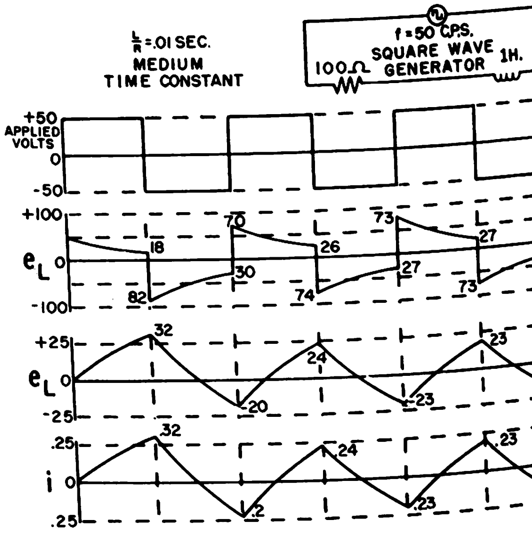

Figure 3-32.—L/R waves when in contains no d-c component.

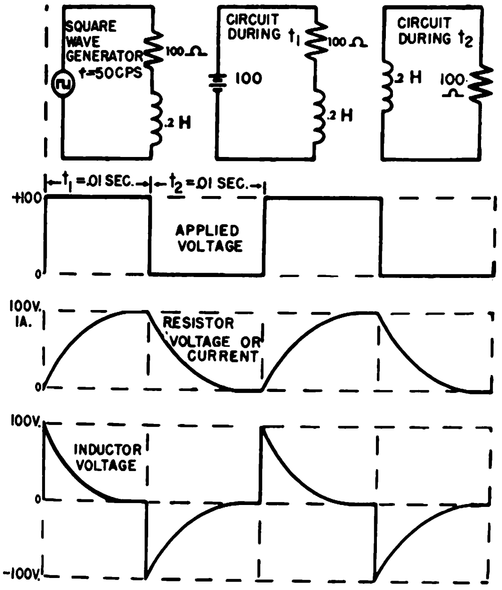

Figure 3-33.—Equivalence in L/R circuit.

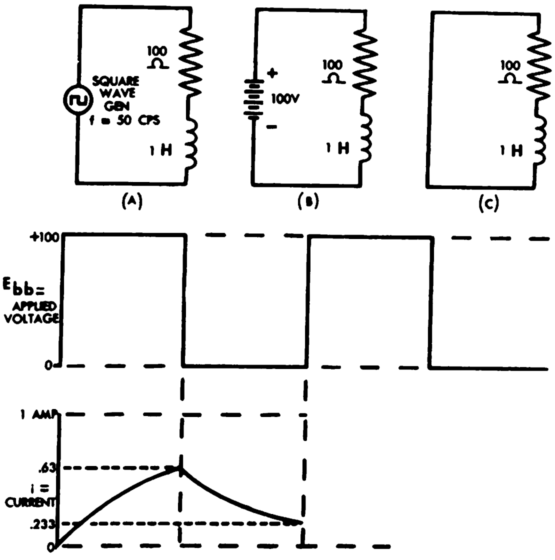

Figure 3-34.—Circuit with voltage and current curves.

To understand how to apply these equivalent circuits in finding either current or voltage at a fixed time, study the following example:

PROBLEM.—In the circuit in figure 3-34 find the current at the end of each of the first two time constants.

Solution:

When the square wave generator is producing the positive half cycle, it applies a constant 100 volts to the circuit in (A) of figure 3-34. The equivalent circuit is shown in (B) of the figure. During this time, current rises toward its maximum $\frac{E}{R}$ value of 1 ampere. Since the time constant is 0.01 second, and since the time of a half cycle is also 0.01 second, the 100 volts is applied for one time constant. Therefore, at the end of one time constant, the current equals 63 percent of maximum, or 0.63 amperes.

The circuit condition when the applied voltage is zero is shown in (C) of figure 3-34. Initially the current is 0.63 ampere, as just determined. The time of this half cycle is also 0.01 second, and likewise one time constant. Since current in an L/R circuit drops to 37 percent of its initial value in one time constant, it here equals 37 percent of 0.63 ampere or 0.233 ampere at the end of the second time constant.

TRIANGULAR WAVES IN RC AND L/R CIRCUITS

Response to Triangular Wave Input

For ease of understanding the effect of triangular waves in L/R and RC circuits, first examine the first rise in voltage when this wave is applied to the RC circuit. (See fig. 3-35 (B).) The voltage wave enlarged several times for easier study, is shown in (C) of the figure. Notice that the voltage starts at zero and keeps on increasing at a constant rate. The triangular waveshape is thus different from that of a square wave in which the voltage rises quickly then levels off. Likewise, the effect of a triangular wave on the capacitor is different from that of a square wave. With a square wave, the capacitor charges exponentially to the value at which the square wave levels off, but with a triangular wave the voltage increases as the capacitor charges toward it (note the triangular shape of the wave), and the capacitor must continually charge toward a new higher value.

Initially when the voltage e_i is applied to the circuit (fig. 3-35 (B)), the current rises with the voltage because the capacitor is initially uncharged. This current charges the capacitor to a voltage that opposes the applied voltage.

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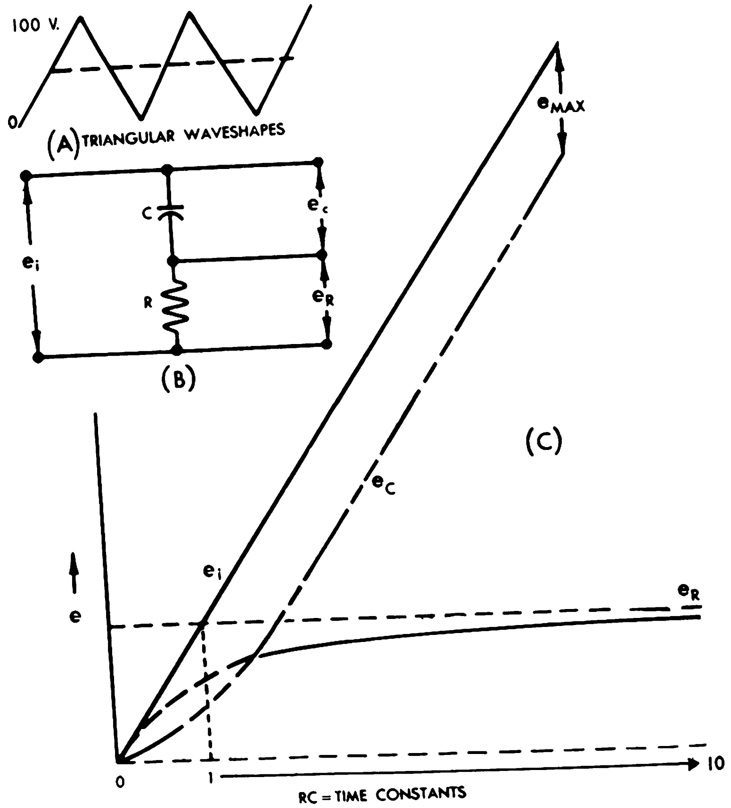

Figure 3-35.—Response of RC circuit to triangular wave input.

This should decrease the current, but since the input voltage is continually increasing, the opposing voltage is more than overcome by the applied voltage, and the current actually increases, but less rapidly than before. As the current increase continues, the capacitor becomes charged to a higher voltage and the rate of current increase falls off until finally the current is high enough to raise the capacitor voltage at the same rate at which the input voltage waveshape increases. At this point, the current becomes constant, and the capacitor voltage slope is essentially the same as the input voltage slope. At this time the constant current through the resistor causes a constant resistor voltage.

Since current increases from zero to a constant value in an RC circuit, its rate of increase is exponential. You can use the curve for e_R as the current curve. Since both the current and voltage are exponential, the current and e_R at the end of one time constant will be 63.2 percent of the voltage applied at that time. After 10 time constants, the current will level off to a value determined by the voltage that is applie at the end of the first time constant; that is, a the value e_{max} shown in figure 3-35.

The maximum value of resistor voltag (e_{max}) is a function of the time constant and th rate of rise. It is expressed by the equatio

$$e_{max} = \frac{\Delta ei}{\Delta t} RC$$

In this equation,

e_{max} = Maximum resistor voltage
R = Resistance in ohms
C = Capacitance in farads
$\frac{\Delta ei}{\Delta t}$ = Rate of change of input voltag volts per second. (The symbo followed by a quantity indica the amount of change in the qu tity.)

Example:

PROBLEM.—Assuming that the triangular waveshape illustrated has a frequency of 50 c.p.s. and is applied to the circuit in figure 3-36, find the maximum resistor voltage.

Solution:

Inspection shows that the change of the input voltage e_i is 100 volts during one half cycle. You can represent this change in input voltage as Δe_i. Since the frequency is 50 c.p.s., one cycle is $\frac{1}{50}$ or 0.02 second. Therefore, the half cycle is 0.01 second long. You can represent the change in time as Δt. Therefore, Δt, during the 100-volt rise, is 0.01 second.

Substituting in equation,

$$e_{max} = \frac{\Delta e_i}{\Delta t} RC$$

$$e_{max} = \frac{100 \times 10^5 \times 0.02 \times 10^{-6}}{0.01}$$

$$e_{max} = \frac{10^2 \times 10^5 \times 2 \times 10^{-2} \times 10^{-6}}{10^{-2}}$$

$$e_{max} = 2 \times 10$$

$$e_{max} = 20 \text{ volts.}$$

The capacitor continues to charge at the same rate until the rise of input voltage ceases. As the voltage abruptly starts decreasing during the second half of the cycle, the charging rate of the capacitor decreases until the input voltage drops to the same value as the capacitor voltage. At this point, the current is zero. As the applied voltage continues to decrease, it falls below the capacitor voltage, and the capacitor starts discharging. This reverses the current, causing a negative voltage across the resistor. Again, the changeover cannot occur any faster than the capacitor can discharge, so the current, and consequently the resistor voltage change is exponential. The decrease in voltage is at the same rate $(\frac{\Delta e_i}{\Delta t})$; so the negative voltage is also 20 volts.

An L/R circuit has the same effect on triangular waveshapes as an RC circuit provided you observe the following changes:

1. The waveshape which appears across the resistor in the RC circuit appears across

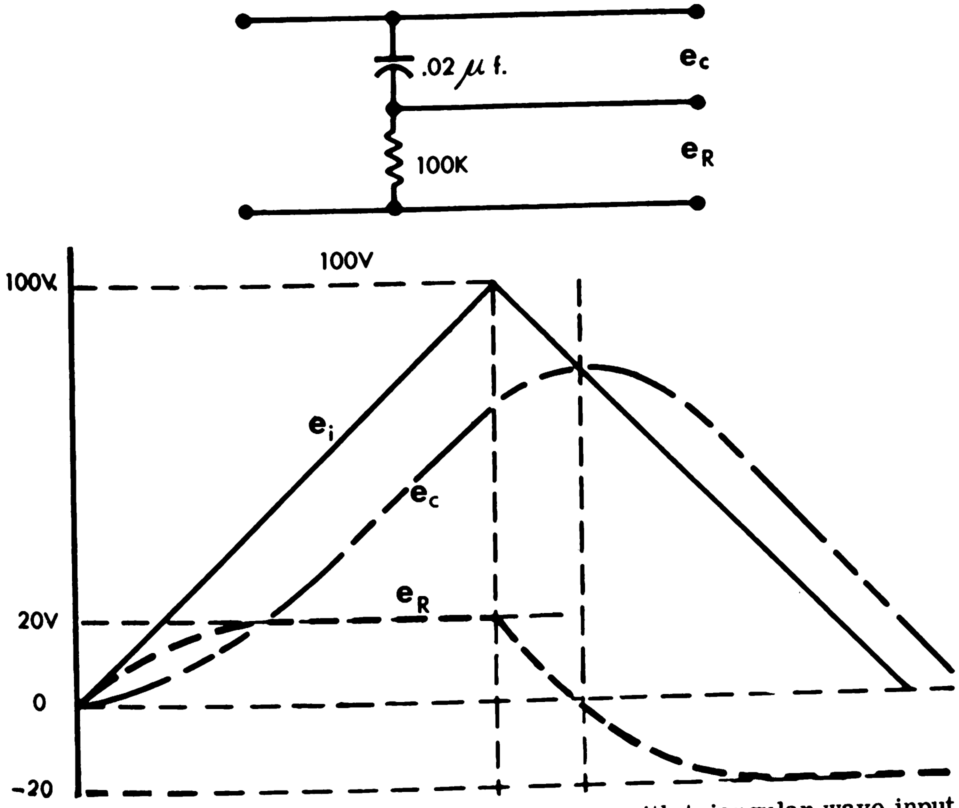

Figure 3-36.—Capacitor and resistor voltages with triangular wave input.

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the inductor in the L/R circuit, while the wave which appears across the capacitor in the RC arrangement appears across the resistor of the L/R combination.

2. The time constant is $\frac{L}{R}$ instead of R x C.
3. The term $\frac{\Delta e_i}{\Delta t} \frac{L}{R}$ is used to obtain the final voltage across the inductor.

When a triangular voltage waveshape is applied to an L/R circuit, the current increases at a constant rate. This, in turn, causes the inductor voltage to become constant after 10 time constants. You can express the maximum inductor voltage by the equation

$$E_L = \frac{\Delta e_i}{\Delta t} \times \frac{L}{R}$$

where E_L is the maximum inductor voltage, $\frac{\Delta e_i}{\Delta t}$ the rate of change of voltage, L the inductance in henrys, and R the resistance in ohms.

PHASE SHIFTING

Review of Phase Relations in RC and RL Circuits

For an understanding of phase splitting and phase shifting the following current and voltage relationships in RC and RL circuits should be recalled:

1. The current and voltage are in phase in a resistor.
2. The current leads the voltage by 90 degrees in a capacitor.
3. The current lags the voltage by 90 degrees in an inductor.
4. When a resistor and capacitor are connected in series, the voltage across the resistor leads the voltage across the capacitor by 90 degrees.
5. When a resistor and an inductor are connected in series, the voltage across the resistor lags the voltage across the inductor by 90 degrees.

Phase-Splitting Circuits

When a resistor and a capacitor are connected in series with an applied sine-wave voltage (fig. 3-37), two output voltages can be obtained which differ in phase by 90 degrees. The voltage across the resistor R is always in phase with the current in R, while the voltage across capacitor C is always 90 degrees out of phase with the current flowing in C. Therefore, the voltage outputs across resistor R and capacitor C (E_R and E_c) are 90 degrees out of phase with each other. Such a circuit, in which two outputs are used, is called a PHASE-SPLITTING CIRCUIT.

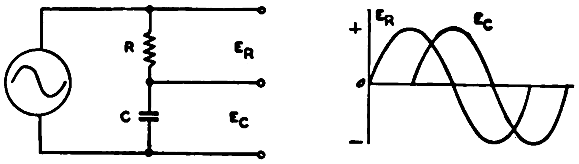

Figure 3-37.—RC phase-splitting circuit.

A similar condition results when a resistor and an inductor are used (fig. 3-38), except that the direction of the phase shift is reversed. Since an inductor in an a-c circuit causes the current to lag the voltage by 90 degrees, the output voltages of the phase-splitting circuit differ by 90 degrees, and the voltage across the resistor lags the voltage across the inductor.

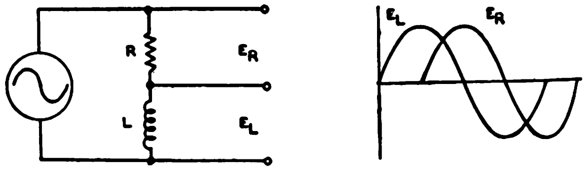

Figure 3-38.—RL phase-splitting circuit.

RC Phase-Shifting Circuit

The RC phase-splitting circuit (fig. 3-37) produces a phase shift or phase difference of 90 degrees between the voltage across the resistor and the voltage across the capacitor. The shift in phase between one of these voltages and the supply voltage depends upon the ratio between the resistance and the reactance in the circuit.

When the resistance is large with respect to the capacitive reactance (fig. 3-39 (A)), most of the opposition to current flow is caused by the resistance, and the effect of the capacitor is small. The current through the circuit is therefore almost in phase with the supply voltage. Since the voltage drop across the resistor is in phase with the current, E_R is almost in phase

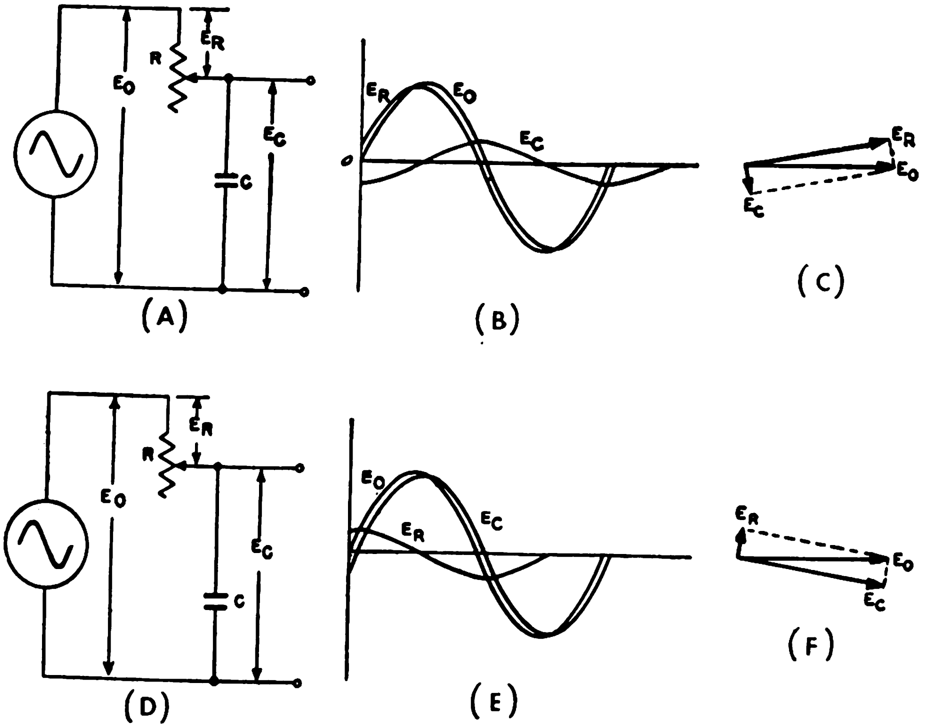

Figure 3-39.—RC phase-shifting network.

with E_O. The output voltage across the capacitor is nearly 90 degrees out of phase with the voltage across the resistor. This phase relationship is shown in figure 3-39 (B) and in the vector diagram (C).

When the resistance is small with respect to the capacitive reactance (fig. 3-39 (D)), most of the opposition to current flow is caused by the capacitor. The current in the circuit therefore leads the applied voltage nearly 90 degrees. The voltage across the resistor, which is in phase with the current, is approximately 90 degrees out of phase with the applied voltage. Therefore, the voltage across the capacitor, which is 90 degrees out of phase with the voltage across the resistor, is nearly in phase with the supply voltage. This phase relationship is shown in (E) and the vector diagram (F).

A phase-shifting circuit, therefore, may be composed of a capacitor and a variable resistor connected across a sine-wave supply voltage. The phase of the output voltage is shifted in relation to the input voltage by variations in the amount of resistance. When the output voltage is across the capacitor, very little resistance in the circuits gives an output almost in phase with the input. A high resistance, on the other hand, gives an output voltage which lags the input voltage.

The output can also be taken across the resistor. In this case the direction of phase shift is reversed. Increased resistance brings the output and input voltages more nearly into phase with each other, while decreased resistance results in a greater degree of phase shift.

RL Phase-Shifting Circuit

Substitution of an inductor for the capacitor in the circuit of figure 3-39 produces an RL phase-shifting circuit (fig. 3-40 (A) and (D)). The phase relations between the input and output voltages can be seen in figure 3-40 (B) and (E) and in the vector diagrams (C) and (F). Since in the case of inductance the current lags the voltage, the voltage across the resistance always lags the voltage across the inductance. The output voltage normally is taken from across the inductance. An increase in the resistance of the phase-shifting circuit increases the difference in phase between input and output voltages. A decrease in the resistance brings the input and

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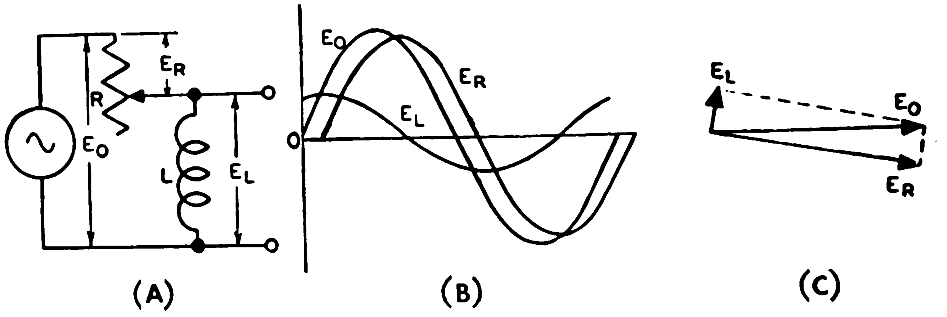
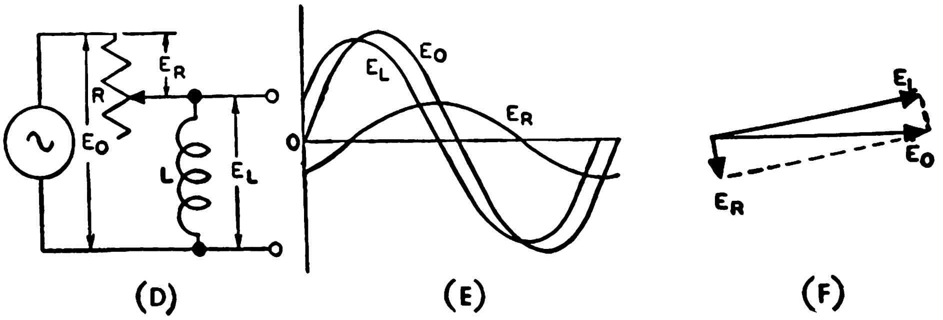


R IS GREATER THAN X_L



X_L IS GREATER THAN R

Figure 3-40.—RL phase-shifting network.

output voltages more nearly into phase with each other.

One disadvantage of the RC and RL types of phase-shifting circuits is that the voltage across either the capacitor or inductor becomes smaller and smaller as the resistance is increased. As a result, these networks are not always satisfactory in a circuit in which a definite output voltage is required. They are practical, however, as networks which can be adjusted to give a definite fixed value of phase shift.

Use of Phase-Shifting Circuits

Phase-shifting circuits are used for two general purposes:

1. To obtain a definite degree of phase shift which may be fixed or adjustable within small limits. For example, this type of circuit is used to correct a shift in phase which otherwise occurs in the equipment. Either the RC or the RL phase-shifting circuit can be used for this purpose.
2. To obtain a shift in phase continuously variable over 360 degrees, which can be adjusted accurately to any desired degree of phase shift, neither an RC nor RL phase-shifting circuit can be used alone. However, an RC circuit is used as a part of the Helmholtz-coil arrangement, which enables a continuously variable degree of phase shift to be obtained at a fixed voltage output.

Rotating Magnetic Field

The Helmholtz-coil phase-shifting circuit depends upon the generation of a rotating magnetic field by its primary coil assembly for its operation. Therefore, the properties of a rotating magnetic field must be considered.

The field around an electromagnet is directly proportional to the current flowing through it, and the polarity of the field is determined by the direction of current flow. When two magnetic fields are produced in the same space, the direction and magnitude of the resultant field is determined by the INTERACTION of the two fields and is the VECTOR SUM of the two fields.

The method of producing a rotating magnetic field by the action of two sets of electromagnets is shown in figure 3-41. At position (A) current

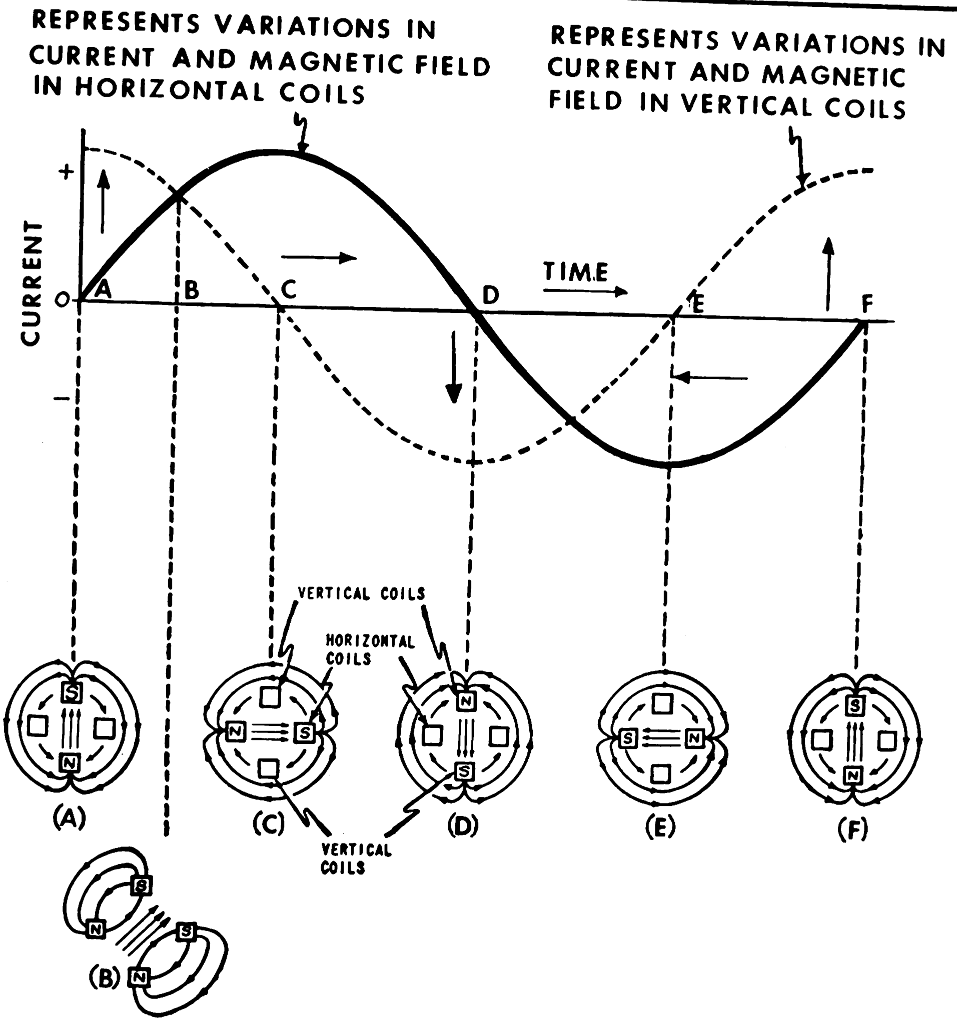

REPRESENTS VARIATIONS IN CURRENT AND MAGNETIC FIELD IN HORIZONTAL COILS
REPRESENTS VARIATIONS IN CURRENT AND MAGNETIC FIELD IN VERTICAL COILS
CURRENT
+
0
−
TIME
A
B
C
D
E
F
VERTICAL COILS
HORIZONTAL COILS
VERTICAL COILS
S
N
(A)
(B)
(C)
(D)
(E)
(F)

Figure 3-41.—Rotating magnetic field in Helmholtz Coil.

flows through the vertical coils, producing a concentrated magnetic field between the upper and lower coils. The lines of force of this field point upward. At position (B) current flows through both sets of coils, producing a distributed magnetic field. The fields produced by each set of coils add to produce lines of force pointing along a diagonal upward and to the right. In other words, the field has rotated 45 degrees in a clockwise direction. At position (C) current in the vertical coils is zero, but current in the horizontal coils is at a maximum. This result is also shown by the curves of current (or field) in which the dotted line refers to the vertical coils and the solid line to the horizontal coils. The magnetic field now points horizontally to the right representing 90 degrees of rotation. Position (D) shows a reversal of the currents from position (A) and therefore represents a 180-degree shift in direction of the field. Likewise position (E) is a reversal of position (C), representing 270-degree rotation. Position (F) is the same as (A), showing the completion of 360 degrees rotation of one revolution of the magnetic-field flux. Thus, if alternating current is made to flow in the vertical and horizontal coils, the field can be caused to rotate uniformly.

Figure 3-42 (A) represents the condition in which the current in the vertical coils is much greater than the current in the horizontal coils. Line A corresponds to the field produced by the vertical coils and line B to the field produced

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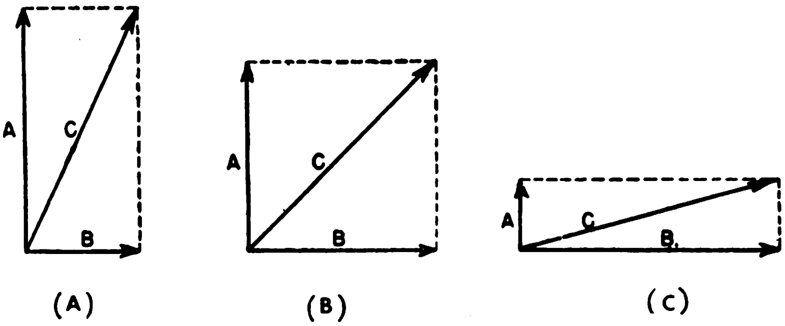

Figure 3-42.—Determination of resultant magnetic fields.

by the horizontal coils. Line C gives the direction and magnitude of the resultant field. In (B), corresponding to figure 3-41 (B), the current producing line A is smaller, but the current producing line B is larger, keeping line C the same length but changing its direction. In (C) the current in the vertical coils is very small, but the current in the horizontal coils is so large that the resultant field, line C, is still the same.

Thus, if the circuit is so adjusted that the currents in the horizontal and vertical coils are always 90 degrees out of phase and their maximum amplitudes are equal, a sine-wave input produces a rotating field in the space between the coils. The direction of this field rotates through 360 degrees for each cycle of an input sine wave, while the magnitude of the field remains constant.

Helmholtz-Coil Phase-Shifting Circuit

The Helmholtz-coil phase-shifting circuit (fig. 3-43) uses two sets of coils for the primary circuit. It obtains the necessary 90 degree difference in phase by means of a capacitor and resistor connected as a FIXED phase-shifting circuit in series with one set of coils. The horizontal-and-vertical-coil circuits must be carefully matched so that the maximum currents in each are equal. Since the horizontal coils are connected across the input line, the current through them lags the input voltage by almost 90 degrees. The same condition would exist in the vertical coils if they, too, were connected directly across the input terminals. But if a capacitor and an adjusting resistor are added in series with the vertical coils, this circuit can be adjusted so that the current through the vertical coils is exactly 90 degrees out of phase with the current in the horizontal coils. This is the condition required to obtain a rotating magnetic field when a sine-wave voltage is applied. A secondary coil S is pivoted in the center of the space between the horizontal and vertical coils so that it can be rotated manually and adjusted to any desired position relative to the primary coils. The rotating magnetic field formed by the currents flowing in the primary coils induces a voltage in the secondary coil. The phase relation between the output voltage and the input voltage

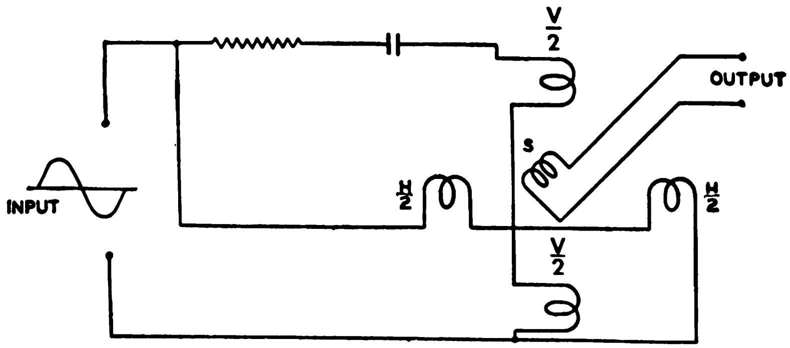

Figure 3-43.—Helmholtz-coil circuit.

depends upon the physical position in which the secondary coil is placed.

In the rotating magnetic field (fig. 3-44), if some fixed point O is used as a reference, the magnetic lines of force point toward O once during each cycle. The same condition is true for any other fixed point such as P. However, since points O and P are separated by some angle (135 degrees in this case), the magnetic field points toward them at different times during each cycle. If the magnetic fields seen at O and P at the same instant are plotted, the resultant curves are 135 degrees out of phase (fig. 3-45). If the secondary coil is so placed that its axis passes through point O and the line voltage is maximum when the lines of force point to O, the electromotive force produced in the coil and the line voltage are maximum at the same time; in other words, they are IN PHASE. However, if the coil is rotated to the position where its axis points to P, a maximum electromotive force is not induced until the magnetic field rotates through 135 degrees. The electromotive force in the secondary or pickup coil and the line voltage are then 135 degrees OUT OF PHASE. Hence, any position may be selected for the axis of the pickup coil to obtain any phase relationship desired between the line voltage and the induced electromotive force. A mechanical rotation of one degree produces a phase difference of one degree between line voltage and induced electromotive force.

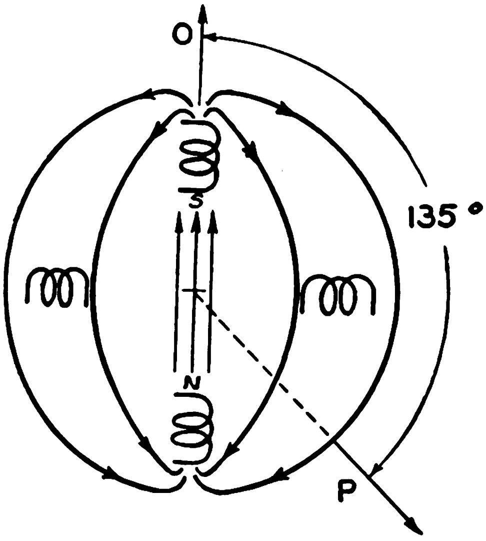

Figure 3-44.—Phase shift between line voltage and induced electromotive force.

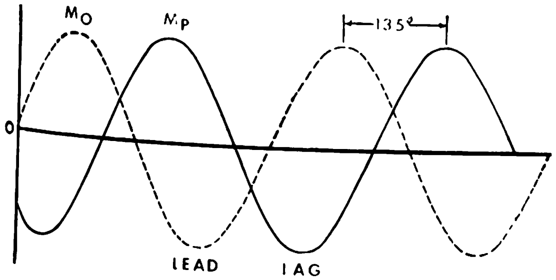

Figure 3-45.—Magnetic fields seen at O and P of figure 3-44.

In order to keep the current in the secondary coil as low as practicable, a high resistance must be connected across the output of the coil. This is necessary since any appreciable current flowing in the secondary coil would produce a magnetic field which would react with the primary field and change the phase relationship between the currents in the two sets of stationary coils. The output of the circuit must be fed to a voltage amplifier.

The Helmholtz-coil phase-shifting circuit provides a means of obtaining any desired degree of phase shift, through the entire cycle of 360 degrees, by the mechanical placement of the secondary coil in a previously calibrated position.

RESISTANCE-CAPACITANCE OSCILLATORS

In an RC oscillator, the frequency is determined by a resistance-capacitance network that provides regenerative coupling between the output and input of a feedback amplifier. No use is made of a tank circuit consisting of inductance and capacitance to control the frequency.

Wien-Bridge Oscillator

TYPICAL CIRCUIT

An oscillator in which a frequency-selective Wien-bridge circuit is used as the resistance-capacitance feedback network is called a Wien-bridge oscillator. One widely used circuit for this type of oscillator is shown in figure 3-46 (A) and (B). In (A) the feedback circuit is drawn to show that the phase-shifting element of the

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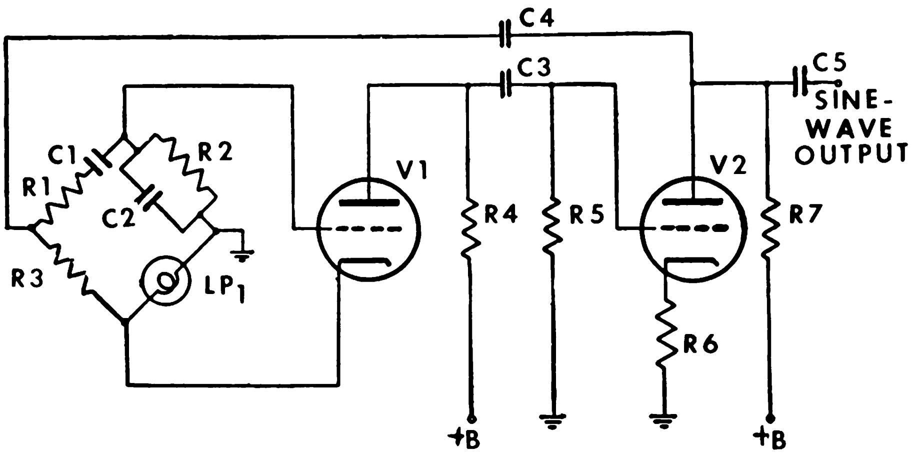
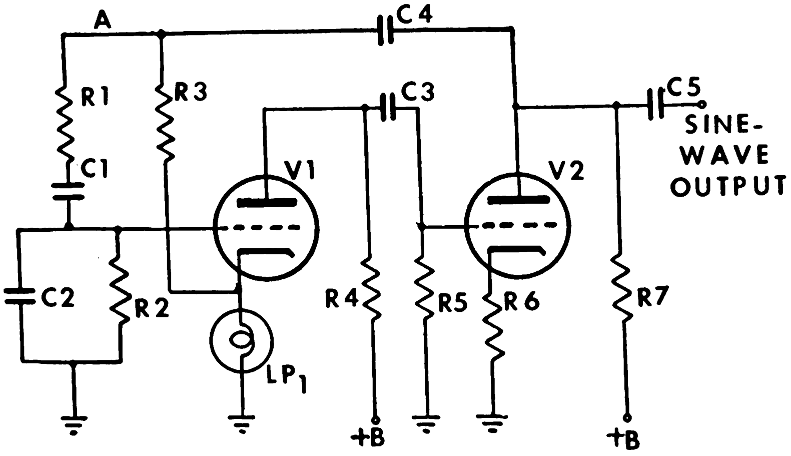


(A) CIRCUIT DRAWN TO SHOW BRIDGE CIRCUIT



(B) CIRCUIT DRAWN TO FACILITATE DISCUSSION

Figure 3-46.—Wein-bridge oscillator.

circuit is a frequency selective bridge. However, it is simpler to use the circuit as shown in (B) for purposes of discussion since the feedback paths are shown more clearly.

ANALYSIS OF OPERATION

Tube V_1 is the oscillator tube. Tube V_2 acts as an amplifier and inverter. Thus, even without the bridge circuit, this system oscillates since any signal that appears at the grid of V_1 is amplified and inverted by both V_1 and V_2. The voltage fed back to the grid of V_1 then must reinforce the initial signal, which causes oscillations to be set up and maintained. However, the system amplifies voltages of a very wide range of frequencies. Voltages of any frequency or of any combination of frequencies can cause oscillation. The bridge circuit is then used to eliminate feedback voltages of all frequencies except the single frequency desired in the output.

The bridge allows a voltage of only one frequency to be effective in the circuit because of the degeneration and phase shift provided by this circuit. Oscillation can take place only at the frequency f_0 which permits the voltage across

R_2, the input signal to V_1, to be in phase with the output voltage of V_2, and for which the positive feedback voltage exceeds the negative feedback voltage. Voltages of any other frequency cause a phase shift between the output of V_2 and the input to V_1 and are attenuated by the high degeneration of the circuit so that the feedback voltage is not adequate to maintain oscillation at a frequency other than f_o.

A degenerative feedback voltage is provided by the voltage divider consisting of R_3 and the lamp LP_1. Since there is no phase shift across this voltage divider, and since the resistances are practically constant for all frequencies, the amplitude of the negative feedback voltage is constant for all the frequencies that may be present in the output of V_2. A curve of the negative feedback voltage is plotted as shown in (A) of figure 3-47.

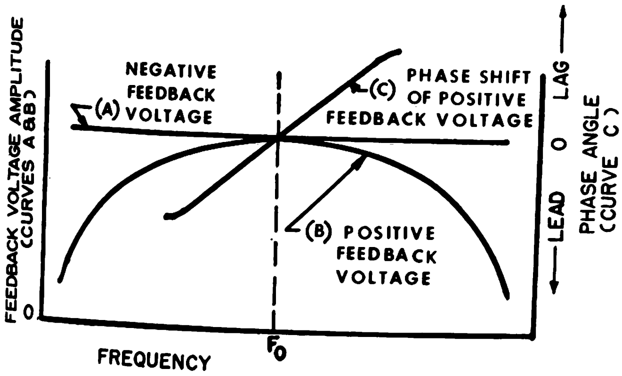


Figure 3-47.—Frequency feedback voltages in Wien-bridge oscillator.

The positive feedback voltage is provided by the voltage divider consisting of R_1, C_1, R_2, and C_2. If the frequency is very high, the reactance of the capacitors is almost zero. In this case resistor R_2 is shunted by a very low reactance, making the voltage between the grid of V_1 and ground almost zero. On the other hand, if the frequency is reduced toward zero the current that can flow through either C_2 or R_2 is reduced to almost zero by the very high reactance of C_1. Therefore, the voltage between the grid of V_1 and ground falls almost to zero. At some intermediate frequency the positive feedback voltage is maximum, as shown by curve B in figure 3-47. The curve is rather flat in the vicinity of f_o, but the phase shift that occurs in the positive feedback circuit permits only a single frequency to be generated.

The voltage across R_2 is in phase with the output voltage of V_2 if $R_1C_1 = R_2C_2$. If the frequency of the output of V_2 increases, the voltage across R_2 tends to lag the voltage at the plate of V_2. If the frequency decreases, the voltage across R_2 leads the output voltage of V_2. Curve C in figure 3-47 shows the phase angle between these two voltages as the frequency of the feedback voltage is varied.

The frequency at which the circuit oscillates is

$$f_o = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}} = \frac{1}{2\pi R_1C_1}$$

At this frequency the positive feedback voltage on the grid of V_1 just equals or barely exceeds the negative feedback voltage on the cathode, and the positive feedback voltage is of the proper phase to sustain oscillation. At any other frequency, the negative feedback voltage is larger than the positive, so that the resultant degeneration of the amplifier suppresses these frequencies.

The lamp LP_1 is used as the cathode resistor of V_1 in order to stabilize the amplitude of oscillation. If for some reason the amplitude of oscillation tends to increase, the current through the lamp tends to increase. When the current increases, the filament of the lamp becomes hotter making its resistance larger. A greater negative feedback voltage is developed across the increased resistance of the hotter lamp filament. Thus more degeneration is provided, which reduces the gain of V_1 and thereby holds the output voltage at a nearly constant amplitude. The waveform is sinusoidal only when the output from V_1 is low in amplitude. By keeping the amplitude low, the lamp serves also to prevent distortion of the sinusoidal waveform of the output.

APPLICATIONS OF WIEN-BRIDGE OSCILLATORS

The Wien-bridge oscillator has many advantages over other types of audio oscillators. For instance, it may conveniently be made to produce a wide range of frequencies. The waveshape is very nearly a true sine wave. Frequency stability is excellent. Finally, the output amplitude is nearly constant over a very wide frequency range.

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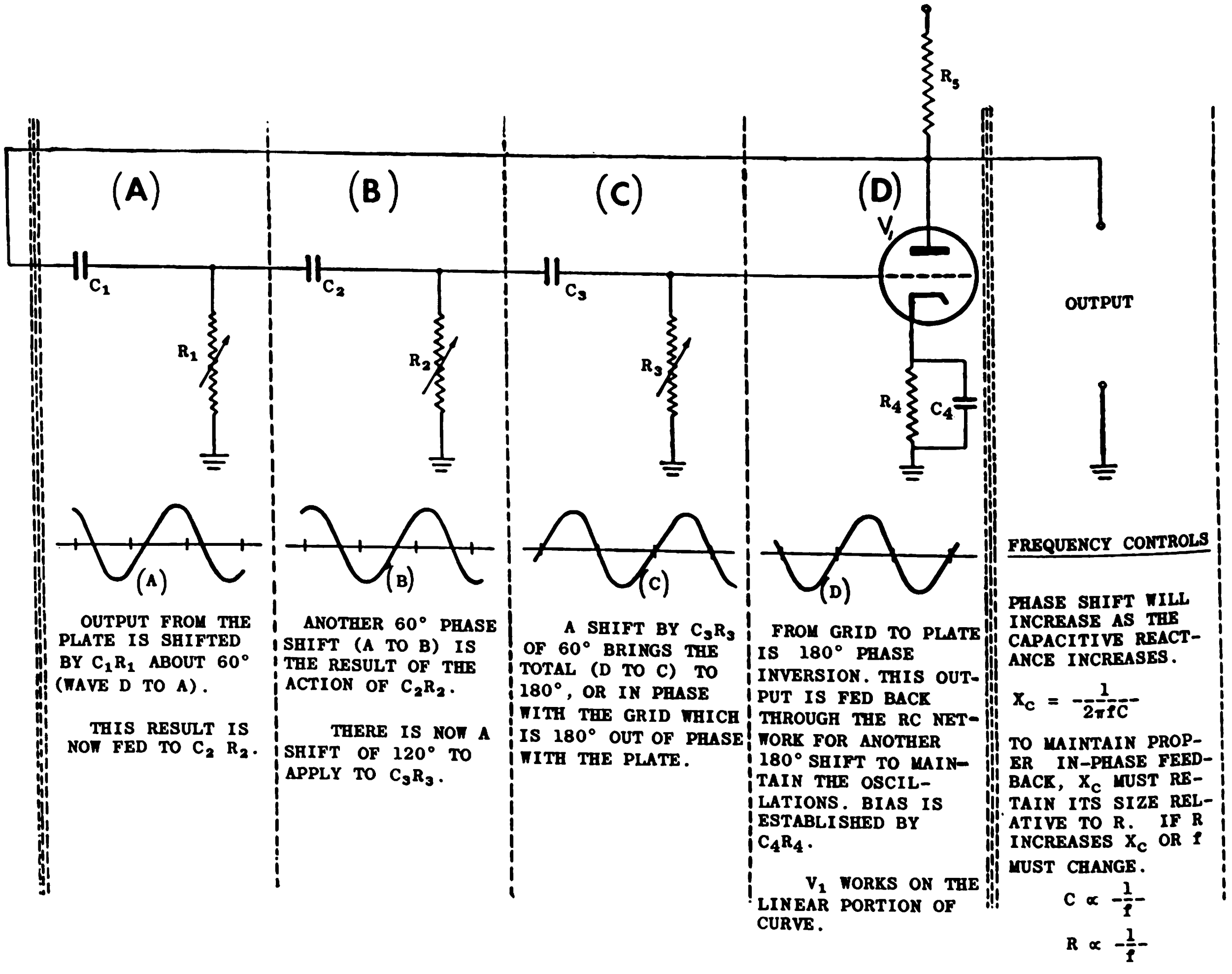
Phase-Shift Oscillator

TYPICAL CIRCUIT

The phase-shift oscillator is a special type of resistance-capacitance tuned oscillator that operates with a single tube. The circuit consists of only one amplifier tube plus a phase-shifting feedback circuit which creates a phase shift in proportion to the frequency passed through it (fig. 3-48). The standard feedback-oscillator circuit requires that the signal from the plate be shifted 180 degrees in order that reinforcing action can take place on the grid to make up for circuit losses. In the phase-shift oscillator this is accomplished by three resistance-capacitance sections.

ANALYSIS OF OPERATION

An L-section resistance-capacitance phase shifter is shown in figure 3-49. An alternating voltage applied to this circuit causes a current to flow in the circuit. The magnitude of this current is determined by the total impedance in the circuit. Since the impedance is capacitative, the current i leads the impressed voltage e by an angle θ shown equal to 60 degrees in figure 3-49 (B) and (C). The voltage drop e_R which occurs across resistor R is in phase with the current that flows through it. Therefore e_R must lead the impressed voltage by an angle θ. If the output of this L-section is impressed on a second similar phase shifter, the phase of the output voltage is shifted an angle θ again. The



OUTPUT FROM THE PLATE IS SHIFTED BY C_1R_1 ABOUT 60° (WAVE D TO A).

THIS RESULT IS NOW FED TO C_2 R_2.

ANOTHER 60° PHASE SHIFT (A TO B) IS THE RESULT OF THE ACTION OF C_2R_2.

THERE IS NOW A SHIFT OF 120° TO APPLY TO C_3R_3.

A SHIFT BY C_3R_3 OF 60° BRINGS THE TOTAL (D TO C) TO 180°, OR IN PHASE WITH THE GRID WHICH IS 180° OUT OF PHASE WITH THE PLATE.

FROM GRID TO PLATE IS 180° PHASE INVERSION. THIS OUTPUT IS FED BACK THROUGH THE RC NETWORK FOR ANOTHER 180° SHIFT TO MAINTAIN THE OSCILLATIONS. BIAS IS ESTABLISHED BY C_4R_4.

V_1 WORKS ON THE LINEAR PORTION OF CURVE.

FREQUENCY CONTROLS

PHASE SHIFT WILL INCREASE AS THE CAPACITIVE REACTANCE INCREASES.

$X_C = \frac{1}{2\pi fC}$

TO MAINTAIN PROPER IN-PHASE FEEDBACK, X_C MUST RETAIN ITS SIZE RELATIVE TO R. IF R INCREASES X_C OR f MUST CHANGE.

$C \propto \frac{1}{f}$

$R \propto \frac{1}{f}$

Figure 3-48.—Phase-shift oscillator.

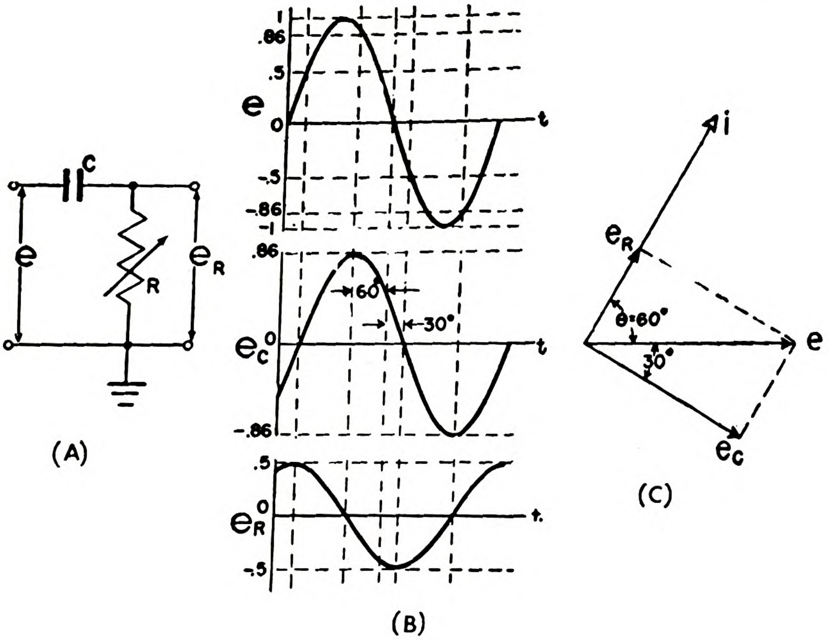


Figure 3-49.—L-section RC phase shifter.

output of this second phase shifter is then leading the first input voltage by an angle 2θ.

If the resistance of R is varied, the phase angle of the current flowing in the circuit also is varied. If R is reduced to zero, the phase angle of the current is 90 degrees, but this action is useless since there is no resistor across which to develop a useful voltage. It is not possible, then, to get a 90-degree phase shift in a single L-section of this type.

In order to obtain a phase shift of 180 degrees, three L-sections must be put in series. Because the reactance of a capacitor varies with frequency, the combination of three L-sections gives a 180-degree phase shift at only one frequency. This enables the circuit of figure 3-48 to operate at only one frequency.

The oscillations are started by any circuit change such as a plate-supply ripple or random tube noise. When a disturbance occurs, the slight change is amplified, inverted 180 degrees at the plate, and inverted another 180 degrees by the RC network to be returned in phase to the grid of the tube for reamplification. The cumulative buildup is repeated until the tube cannot amplify further because of plate-current saturation.

If each of the three L-sections A, B, and C (fig. 3-50) produces a 60-degree phase shift, the input voltage to the grid of the tube is shifted 180 degrees relative to the output voltage at the plate. The output of section A leads the plate voltage by 60 degrees. If the output of section A is impressed on section B, the output of this circuit leads the plate voltage by two times 60 degrees or 120 degrees. In the same way, section C adds another 60-degree shift in phase and the input to the grid therefore leads the output from the plate by 180 degrees.

The waveform of the output of the phase-shift oscillator is very nearly sinusoidal if the bias on the tube is adjusted to a value which barely allows oscillations to be maintained. The frequency stability of the circuit is then also very good.

APPLICATIONS OF PHASE-SHIFT OSCILLATORS

The phase-shift oscillator is useful primarily in applications where a fixed frequency is desired, but the frequency can be changed by changing any of the phase-shifting capacitors or resistors. In order to INCREASE THE FREQUENCY, either the resistance or the capacitance must be DECREASED. TO DECREASE THE FREQUENCY, the resistance or capacitance

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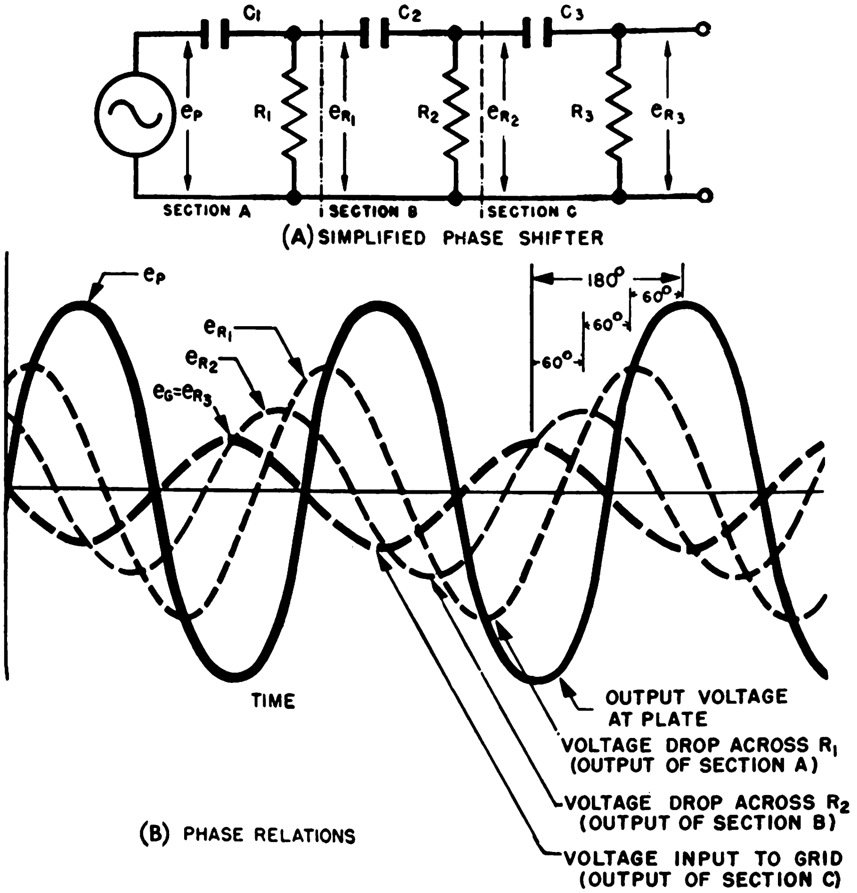
C1
C2
C3
eP
R1
eR1
R2
eR2
R3
eR3
SECTION A
SECTION B
SECTION C
(A) SIMPLIFIED PHASE SHIFTER
eP
eR1
eR2
eG=eR3
180°
60°
60°
60°
TIME
OUTPUT VOLTAGE AT PLATE
VOLTAGE DROP ACROSS R1 (OUTPUT OF SECTION A)
VOLTAGE DROP ACROSS R2 (OUTPUT OF SECTION B)
VOLTAGE INPUT TO GRID (OUTPUT OF SECTION C)
(B) PHASE RELATIONS

Figure 3-50.—Phase-shifting circuit.

must be INCREASED. The angle that each L-section shifts the phase is dependent on the ratio of

$$\frac{X_C}{R} = \frac{1}{2\pi fCR}$$

If the value of this fraction is to remain constant, either C or R must be increased when the frequency is decreased.

Another type of phase-shift oscillator is shown in figure 3-51. The bridge circuit, consisting of R_1, R_2, R_3, C_1, C_2, and C_3, is so proportioned that at only one frequency is the output voltage across R_4 180 degrees out of phase with the voltage at the plate of the tube. The reactance of the several capacitors involved changes sufficiently with a change of frequency so that the phase shift produced is 180 degrees. This will occur at only one frequency. Voltage of other frequencies, therefore, are fed back the grid out of phase with the existing grid si nal, and are canceled by being amplified out phase.

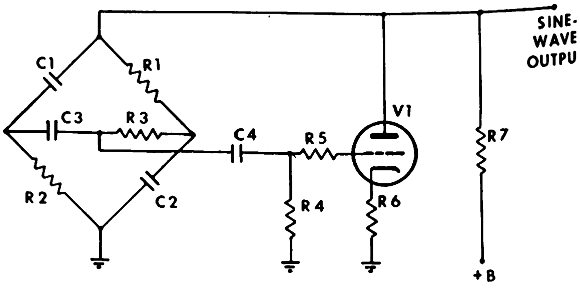

Figure 3-51.—Bridge-type phase-shift oscillator.

QUIZ

1. A peaked waveform is composed of a fundamental sine wave and an infinite number of
   a. odd harmonics in phase
   b. even harmonics in phase
   c. both odd and even harmonics in phase
   d. odd harmonics out of phase

2. With reference to an applied waveform, what is considered to be a long time constant?
   a. One-tenth the time of the longest portion
   b. Ten times the shortest portion
   c. Ten times the longest portion
   d. The time of the longest portion

3. What is a differentiator or integrator circuit?
   a. A coupling circuit
   b. A distortion circuit
   c. A phase splitting circuit
   d. A parallel RC circuit

4. What wave shape will be obtained across L in a long L/R circuit with a square wave applied?
   a. Square wave
   b. Peaked wave
   c. Sawtooth wave
   d. Sine wave

5. Assume that the time constant of a circuit is to remain unchanged. Which of the following is a true statement?
   a. If R is increased, C must also be increased
   b. If R is increased, C must be decreased
   c. If C is increased, R may be either decreased or increased
   d. If C is increased, R may be either decreased or unchanged, but must not be increased

6. How can the L/R time of a circuit be increased?
   a. Increase L
   b. Increase R
   c. Decrease frequency
   d. Increase frequency

7. What is the instantaneous value of current in a series L/R circuit after one L/R time?
   a. Maximum
   b. Minimum
   c. 63 percent of maximum
   d. 37 percent of maximum

8. What is the primary use of a short R-C circuit?
   a. For coupling a d-c voltage
   b. For blocking an a-c voltage
   c. For phase shifting
   d. For waveform shaping

9. What is the primary use of a long RC circuit?
   a. For coupling a d-c voltage
   b. For coupling an a-c voltage
   c. For shaping
   d. To serve as a voltage divider at low frequencies

10. A sawtooth waveform is composed of a fundamental sine wave and an infinite number of
    a. odd harmonics in phase
    b. even harmonics in phase
    c. both odd and even harmonics in phase
    d. odd harmonics out of phase

11. What effect will increasing R in an L/R circuit have on resistor waveform?
    a. No effect
    b. It will more closely resemble the input
    c. It will cause more distortion
    d. It will resemble the input less

12. What effect on resistor waveform will increasing R in an RC circuit have?
    a. No effect
    b. It will more closely resemble the input
    c. It will cause more distortion
    d. It will resemble the input less

13. What is the rate of charge or discharge of a capacitor in a series RC circuit?
    a. Exponential
    b. Linear from 0 percent to 100 percent
    c. Charges/discharges 100 percent in one RC time
    d. Same as in a parallel R-C circuit

14. What wave shape will be obtained across the resistor in a long RC circuit with a square wave applied?
    a. Square wave
    b. Peaked wave
    c. Sawtooth wave
    d. Sine wave

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15. With reference to an applied waveform, what is considered to be a short time constant?
    a. One-tenth the time of the shortest portion
    b. The time of the shortest portion
    c. 5 times the shortest portion
    d. One-tenth the time of the longest portion

16. What wave shape will be obtained across L in a short L/R circuit with a square wave applied?
    a. Square wave
    b. Peaked wave
    c. Sawtooth wave
    d. Sine wave

17. What wave shape will be obtained across the resistor in a short RC circuit, with a square wave applied?
    a. Square wave
    b. Peaked wave
    c. Sawtooth wave
    d. Sine wave

18. Voltage waveforms across an inductor in an L/R circuit, and across a resistor in an RC circuit
    a. show opposite results to a given waveform
    b. show the same results to a given waveform
    c. cannot be compared
    d. show no similarity

19. A square wave is composed of a fundamen
    sine wave and an infinite number of
    a. odd harmonics in phase
    b. even harmonics in phase
    c. both odd and even harmonics in pha
    d. odd harmonics out of phase

20. What is the instantaneous value of curr
    in a series RC circuit after one RC tim
    a. Maximum
    b. Minimum
    c. 63 percent of maximum
    d. 37 percent of maximum

21. The universal time constant chart can
    used with
    a. R and C combinations of short time c
       stant circuits
    b. R and C combinations of long time c
       stant circuits
    c. R and C combinations of medium ti
       constant circuits
    d. all of the above

CHAPTER 4

SPECIAL CIRCUITS

Limiters and Clippers

The term limiting refers to the removal by electronic means of one extremity or the other of an input wave. Circuits which perform this function are referred to as LIMITERS or CLIPPERS.

Limiters are useful in waveshaping circuits where it is desirable to square off the extremities of the applied signal. A sine wave may be applied to a limiter circuit to obtain a rectangular wave. A peaked wave may be applied to a limiter to eliminate either the positive or the negative peaks from the output. In frequency modulation receivers, where it is necessary to limit the amplitude of the signal applied to the detection system to a constant value, limiter circuits are employed. Limiters find application as protective devices in circuits in which the input voltage to a stage must be prevented from swinging too far in the positive or the negative direction.

SERIES-AND PARALLEL-DIODE LIMITERS

Series-Diode Limiting

The characteristics of a diode are such that the tube conducts only when the plate is at a positive potential with RESPECT TO THE CATHODE or, in other words, when the cathode is negative with respect to the plate. If the cathode is held at ground potential, the plate need only be positive with respect to ground for current to pass through the diode. A positive potential may be placed on the cathode, in which case the tube does not conduct until the voltage on the plate rises above that positive value. Likewise, the cathode may be held at a negative potential, and the tube conducts while the plate is positive and continues to conduct while the plate is at a negative potential which is less negative than the cathode. As the plate becomes more positive with respect to the cathode, the current through the tube increases and the plate-to-cathode resistance decreases rapidly from an open circuit to an average value on the order of 500 ohms.

The series-diode limiter (fig. 4-1) is commonly used to limit the positive half of a sine wave. The rectifying characteristics of the diode are utilized so that it may be considered as a switch. This is justified if the value of R is very large as compared to the resistance of the diode when conducting. Thus, in figure 4-1 the output voltage remains at zero throughout the positive half cycle of the input since the diode switch is open and no current flows through R. During the negative half cycle, on the other hand, the cathode is negative with respect to the plate and the tube conducts. The switch is closed and the output voltage developed across R follows the applied voltage and, neglecting the very small drop across the tube e_p, is essentially equal to it.

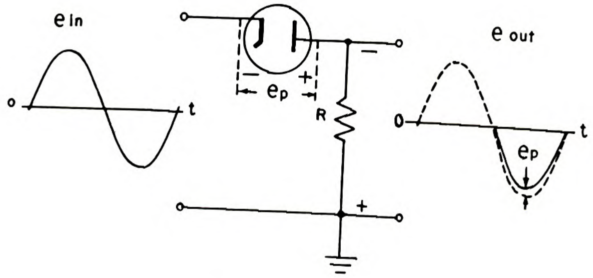

Figure 4-1.—Series diode used to limit positive signals.

In a similar manner the same circuit, with the diode connections reversed, may be used to limit the negative swing of the input voltage. This application is illustrated in figure 4-2. The diode switch is closed during the positive swing

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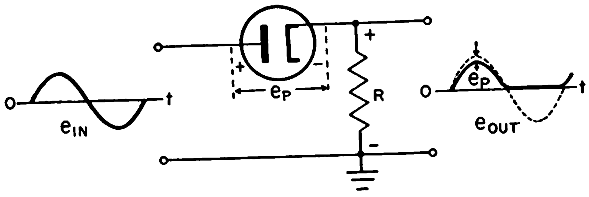


Figure 4-2.—Series diode used to limit negative signals.

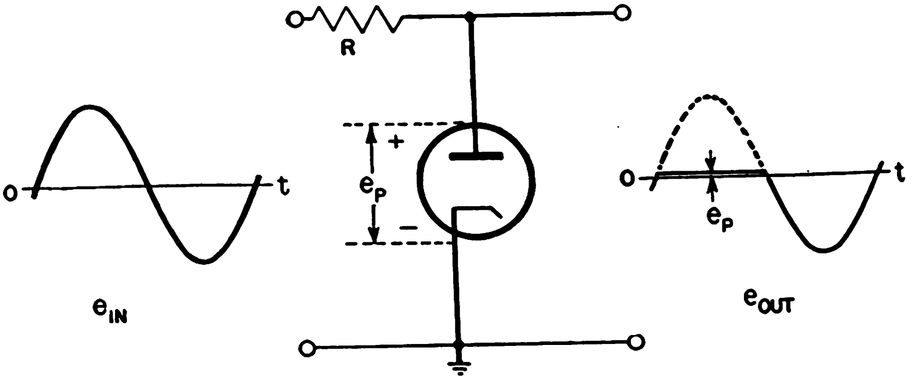
of the input voltage and is open during the negative swing. Thus a voltage is developed across R during the positive half cycle only.

Parallel-Diode Limiting

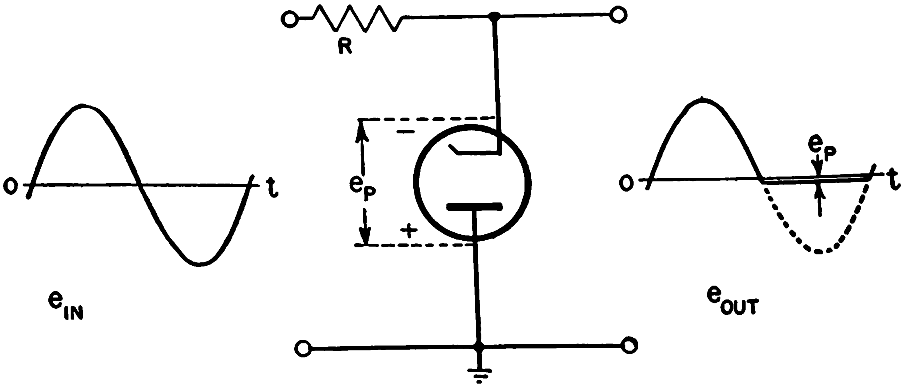
An alternate method of employing diodes in limiter circuits is shown in (A) and (B) of figure 4-3. The tubes in the two circuits are connected in parallel with the load, which is assumed to be a very high impedance so that the output current is negligible.

In figure 4-3 (A) the diode is connected so as to limit the positive signals at approximately ground potential. Since the cathode is held at ground potential, the diode conducts throughout the entire positive half cycle. Current flows through the tube and through the series resistor R. As R is large as compared to the plate-to-cathode resistance of the diode, essentially the entire input voltage is developed across R and the output voltage is only the very low voltage drop across the diode, ep. This may be a negligible positive voltage depending on the ratio of R to the diode resistance. On the negative swing of the input the diode does not conduct; thus no current flows through R and the output voltage equals the input.

In figure 4-3 (B) the plate of the diode is held at ground potential so that the tube does not conduct during the positive half cycle. Thus



(A) POSITIVE LIMITING



(B) NEGATIVE LIMITING

Figure 4-3.—Parallel-diode limiter circuits.

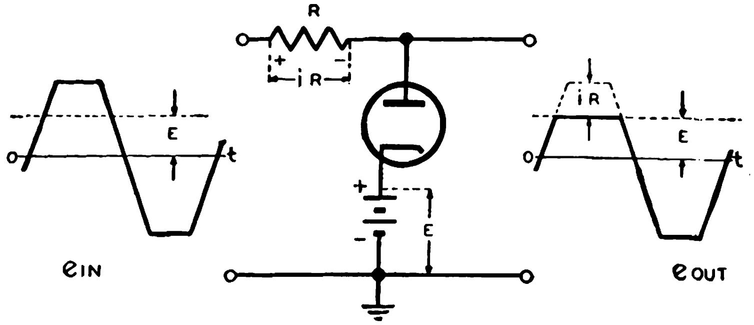
the output voltage equals the input. During the negative half cycle of the input voltage the cathode is negative with respect to the plate and the diode conducts. The diode current flows through the series resistor R across which essentially the entire input voltage is developed. The output voltage is limited to the very low voltage drop across the tube. This low negative voltage as a rule may be neglected, and the outputs may be considered as being limited at essentially ground potential as a result of the switching action of the diode.

Biasing the Limiter

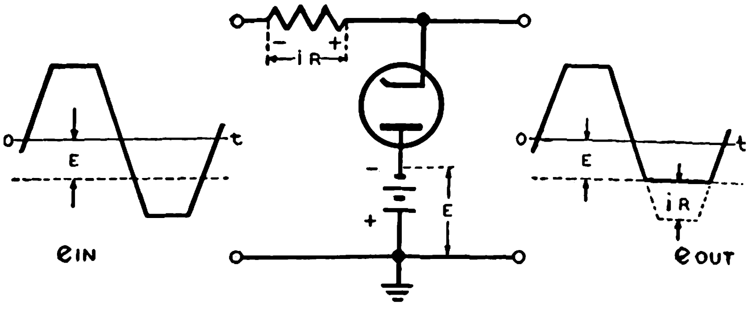
An input voltage can be limited to any desirable positive or negative value by holding the proper diode electrode at that voltage by means of a battery or biasing resistor. Two such circuits are shown in figure 4-4.

The cathode of the diode in figure 4-4 (A) is more positive than the plate by the value of E when no signal is applied at the input. As long as the input voltage remains less positive than the battery voltage E, the diode acts as an open switch and the output equals the input. If the input increases to a value greater than E, the diode conducts and behaves as a closed switch which effectively connects the upper output terminal to the positive terminal of the battery. Thus during this portion of the input cycle the output voltage equals E, and the difference between e_{in} and E appears as an IR drop across the resistor R, neglecting e_p (voltage drop across the tube).

The plate of the diode (fig. 4-4 (B)) is negative by the value of battery voltage E. Thus, as long as the input is positive or is less negative than E, the diode is an open switch and the output voltage e_{out} is equal to the input. When the input becomes more negative than E, the diode conducts and effectively connects the upper output terminal to the negative terminal of the battery. During this portion of the input cycle,



(A) POSITIVE LIMITING



(B) NEGATIVE LIMITING

Figure 4-4.—Parallel diodes limiting above and below ground.

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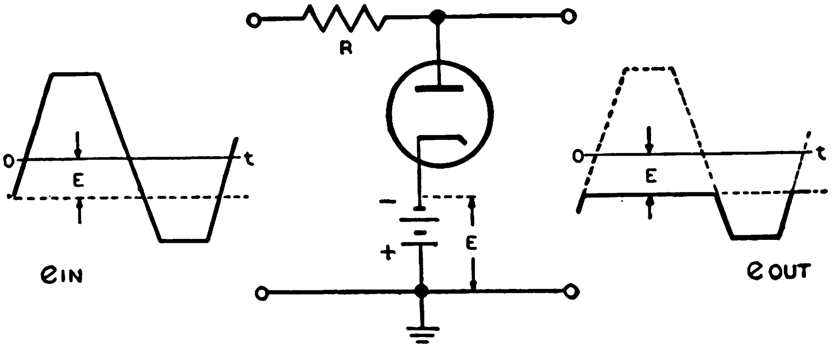
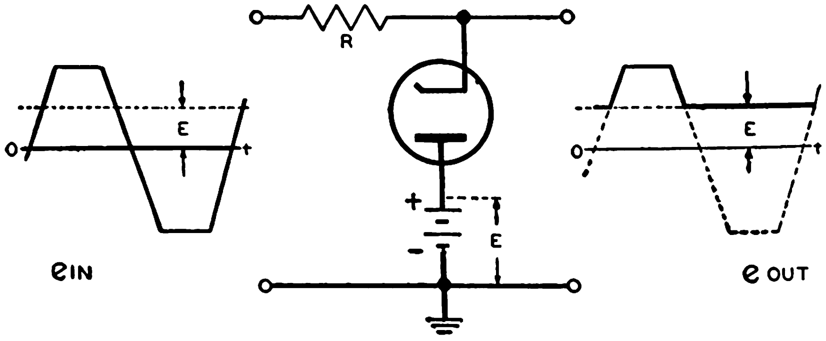
e_{out} equals E and the difference between e_{in} and E appears as an IR drop across R.

It is sometimes desirable to pass only the positive or negative extremity of a waveform on to a succeeding stage. To accomplish this the parallel-diode limiters shown in figure 4-5 can be employed. In (A) the entire portion of the input waveform above the negative potential E causes the diode to conduct, thus producing an output voltage which varies between the negative level of E and the negative extremity of the input. In (B) the diode conducts during the entire portion of the input waveform which is below the positive potential of E. The output voltage then varies between the positive level of E and the positive extremity of the input waveform. In either case the difference between the value of E and ein during the time the diode conducts is represented by the IR drop across the series resistor R.



(A) NEGATIVE PEAKS RETAINED



(B) POSITIVE PEAKS RETAINED

Figure 4-5.—Parallel-diode limiters which pass peaks only.

Crystal-Diode Limiting

Although most circuits use diode vacuum tubes in limiter circuits, the crystal diode or silicon crystal rectifier is becoming increasingly popular for limiting. The crystal diode usually consists of a small piece of silicon and a pointed tungsten wire contactor. It operates by virtue of the fact that it passes little current from the crystal to the wire because of high resistance, but permits current to flow readily from wire to the crystal when an a-c voltage is plied to its input terminals. Since, like a di vacuum tube, it conducts more current in direction than in the other, the crystal assem often is called a CRYSTAL DIODE. Not onl the crystal almost as efficient as the vacu tube, but it requires no heater voltage an entirely free of interference from the po supply frequency. It may be used in any of diode limiter circuits previously described. The one illustrated in figure 4-6 is for use in limiting or clipping the positive cycle of the input waveform.

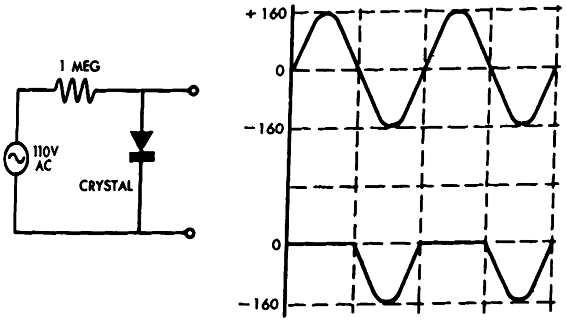


Figure 4-6.—Positive crystal limiters.

Double-Diode Limiting

It is possible to limit both amplitude extremities of an input waveform at any desirable level by placing two diodes in parallel in the limiter circuit. In figure 4-7, the diode V_1 is made to conduct whenever the input voltage e_{in} reaches a higher positive value than E_1, thus limiting the positive half cycle to the value of E_1. The diode V_2 is made to conduct whenever the input reaches a higher negative value than E_2, thus limiting the negative half cycle to the value of E_2. The circuit represents a simple method of producing a satisfactory square-wave output with a sine-wave input voltage.

AMPLIFIER TUBES AS LIMITERS

Grid Limiting Action

The grid-cathode circuit of a triode, tetrode, or pentode may be employed as a limiter circuit in exactly the same way as the plate-cathode circuit of the diode limiter illustrated in figures 4-3 and 4-4. By inserting a series grid resistor, as shown in figure 4-8, which is very large compared to the grid-to-cathode resistance when grid current flows, essentially the entire positive half cycle of the input voltage is limited to the voltage level of the cathode. For example, the grid-to-cathode resistance may drop from an infinite value, when the grid is negative with respect to the cathode,

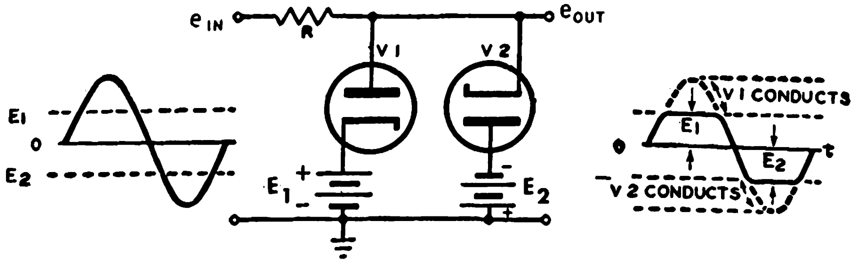


Figure 4-7.—Double-diode limiter circuit.

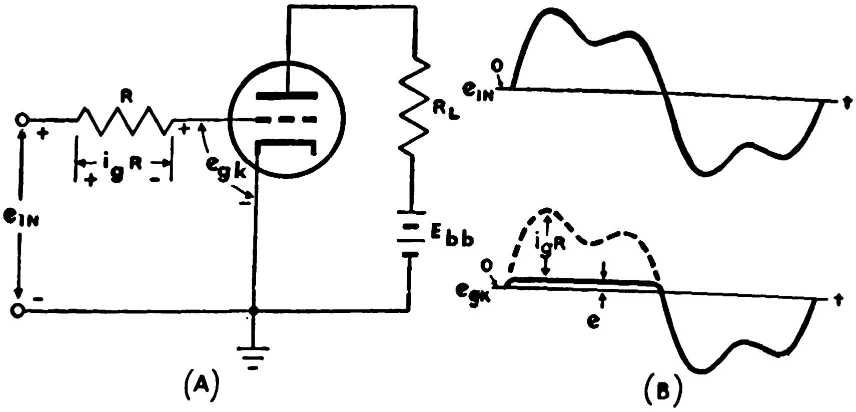


Figure 4-8.—Unbiased grid-limiter circuit.

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to a value on the order of 1,000 ohms, when the grid attempts to become positive with respect to the cathode. If a 1-megohm resistor is placed in series with the grid, the drop across the 1,000-ohm R_{gk} is negligible as compared to that which is developed across the 1-megohm resistor by the flow of grid current.

The grid-limiter circuit shown in figure 4-8 (A) is held normally at zero bias. During the positive portion of the input signal the grid attempts to swing positive. Grid current flows through the resistor R, developing an i_gR drop of such polarity as to oppose the positive input voltage. Since the full input voltage must appear as the sum of the drop across R and R_{gk}, the larger R is with respect to R_{gk}, the nearer the voltage on the grid is limited to that of the cathode. The i_gR drop may be considered as an automatic bias developed during the part of the input which causes grid current to flow.

Alternate circuits for limiting the positive peaks of the input voltage are shown in figures 4-9 and 4-10. In figure 4-9 (A) the tube is biased by the negative potential E supplied to the grid, with the cathode returned to ground. No grid current flows until the input signal e_{in} rises sufficiently to equal and effectively remove the biasing voltage E. Any further rise of e_{in} drives the grid positive with respect to the cathode, and grid current flow limits the signal on the grid by virtue of the i_gR drop across R.

Limiting with self-bias is shown in figure 4-10 (A). Bias is developed between grid and cathode by the flow of plate current through the cathode resistance R_k which is bypassed by the large capacitor C_k. The grid is held normally at ground potential and thus is negative with respect to the cathode. Any positive signal e_{in} must drive the grid positive by an amount equal to the value of E before the biasing effect of R_k is removed. This is shown by e_g waveform in figure 4-10. A further rise of the input voltage produces grid current which results in the limiting of the voltage at the grid. The grid-to-cathode voltage e_gK in figure 4-10 (B) illustrates the effect of R in preventing the grid from swinging appreciably above the cathode potential.

Saturation Limiting

Whenever a series-limiting resistor is used in the grid circuit, the grid cannot be driven

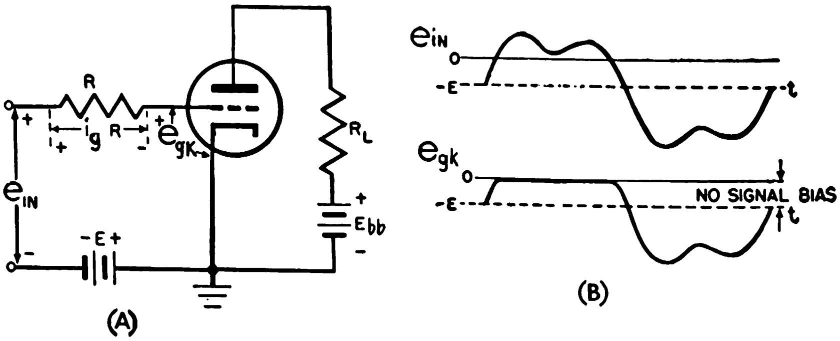

Figure 4-9.—Grid limiter with cathode grounded and grid biased by negative voltage.

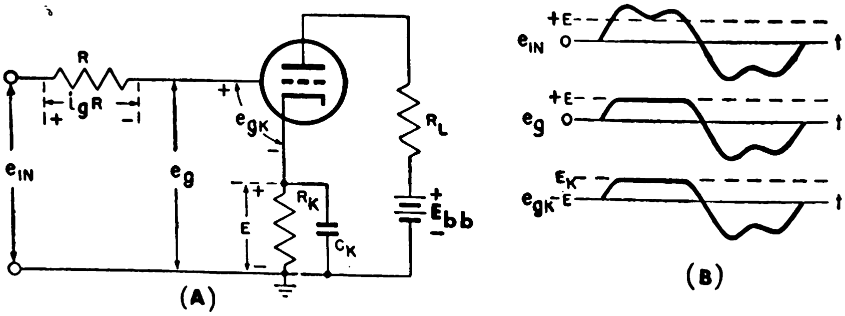

Figure 4-10.—Grid limiter with automatic cathode bias.

to an appreciable positive voltage and, despite the positive amplitude of the input voltage, the maximum plate current which flows is that determined by the plate supply E_{bb} and the resistance of the plate circuit at zero bias. Thus the minimum plate voltage is determined by the limiting action in the grid circuit. These plate-current and plate-voltage relationships are shown in figure 4-11.

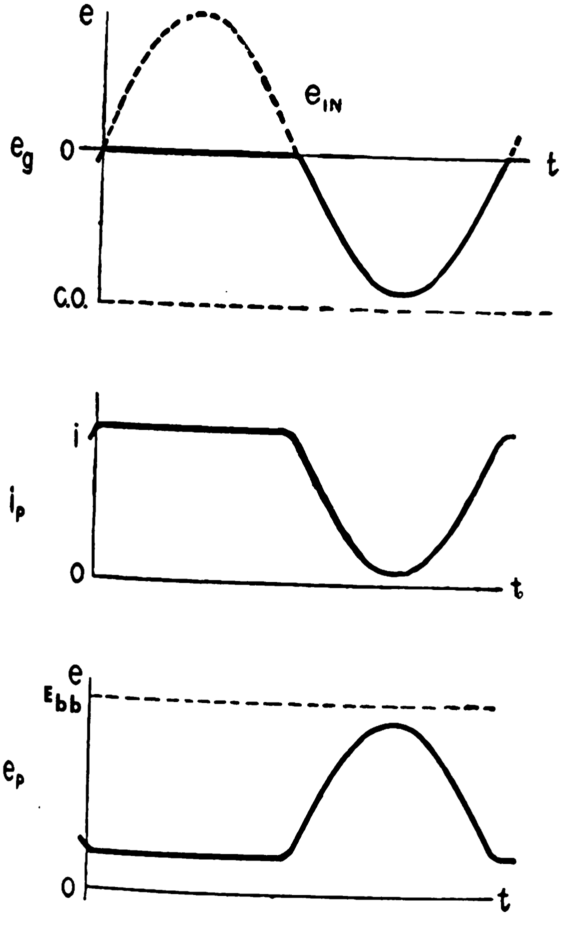

Figure 4-11.—Effect of grid limiting on plate current and plate voltage.

The grid-limiting resistor may be omitted, if the input signal comes from a low-impedance high-power source, and limiting in the plate circuit may still be realized. This is due to plate-current saturation and is usually referred to as saturation limiting. Plate-current saturation should not be confused with emission saturation since in tubes using oxide-coated cathodes there is no definite saturation value of emission current.

By using a large value of plate-load resistance R_L and a low plate-supply voltage E_{bb}, saturation limiting may be produced by a relatively low amplitude of positive grid voltage. In any case, however, the plate current can never exceed the value E_{bb}/R_L. In an actual circuit some small positive voltage must remain on this plate to attract the electrons from the cathode, and the saturation plate current never quite equals E_{bb}/R_L. In other words, there remains across the tube a low voltage drop when the plate current is at saturation, since the plate-to-cathode resistance at saturation does not decrease to absolute zero.

In figure 4-12 (A) the i_p vs. e_p characteristic of a triode is used to illustrate the effect of saturation limiting on the plate voltage. In (B) the input signal applied to the grid, which is normally at zero bias, is not of sufficient amplitude to drive the tube to cutoff on the negative swing but causes the plate current to saturate on the positive swing. The dotted extension of the loadline describes the tube during the positive portion of the input cycle. The maximum plate current shown in (C) cannot exceed the value E_{bb}/R_L no matter how high the amplitude of the positive grid signal, and is actually slightly less because of the low-saturation plate resistance which remains in series with the load. In (D) the maximum plate current defines the lowest value to which the plate voltage can fall. During the remaining portion of the input cycle, the grid controls the flow of plate current which in turn determines the shape of plate-voltage waveform.

The results of saturation limiting are similar to those of grid limiting in that the negative-going portion of the plate voltage is affected. These are compared in figure 4-13. Saturation limiting has the advantage of producing an output wave of greater amplitude, but it has the disadvantage of requiring considerably more power to drive the grid.

Cutoff Limiting

Electron current through a vacuum tube can flow only from cathode to plate and not from plate to cathode. When the grid is driven to cutoff, the plate current is decreased to zero and remains at zero during the time the grid is below cutoff. Since no current flows through

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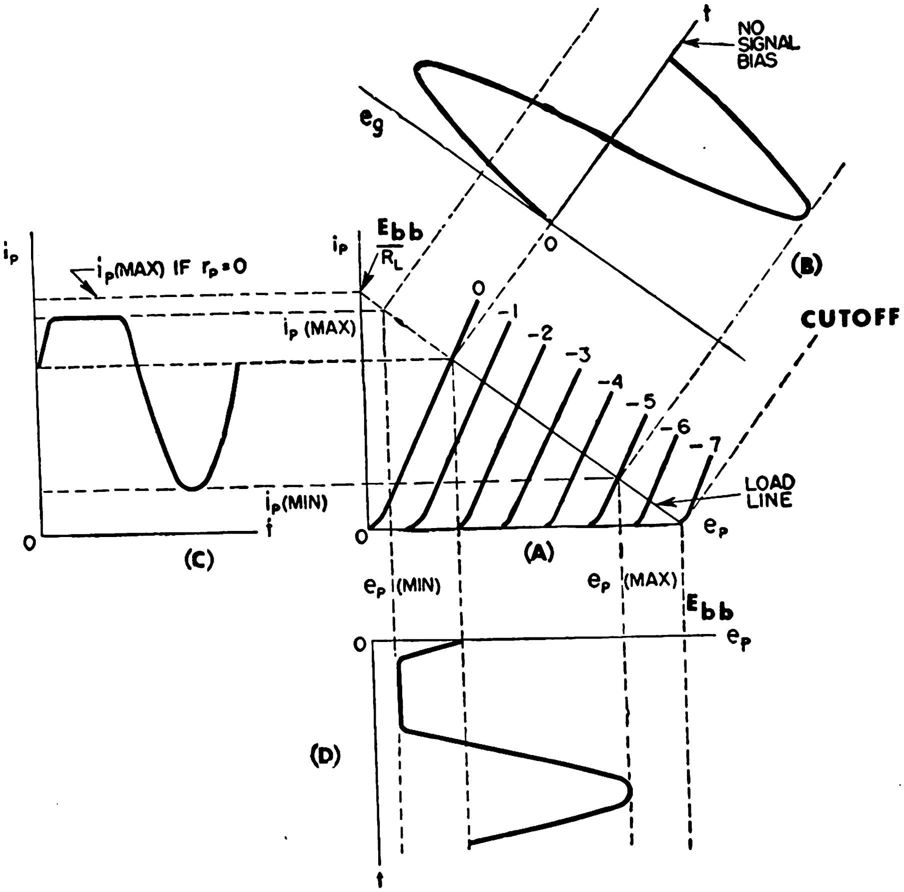

Figure 4-12.—Tube characteristics (i_p vs. e_p) illustrating saturation limiting.

the plate circuit when the tube is cut off, there is no voltage developed across the load resistance, and the plate is maintained at the full value of the plate-supply voltage. Thus, a type of limiting is achieved in which the positive extreme of the plate waveform is flattened as a result of driving the grid beyond cutoff.

The cutoff voltage may be defined as the negative voltage with respect to the cathode, to which the grid must be driven in order to prevent the flow of plate current. For any given type of tube this voltage level is a function of the plate-supply voltage and in the case of TRIODES may be approximated by the expression

$$E_{co} = \frac{E_{bb}}{\mu}$$

where E_{bb} is the plate-supply voltage and μ is the amplification factor of the tube. This relation is NOT valid in the cases of tetrodes a pentodes.

In figure 4-14 the i_p vs. e_p characterist of a triode is used to illustrate the limiti effect caused by driving the grid of an amplifi beyond cutoff. The grid normally is biased minus 5 volts by the steady drop across R (See (A) of fig. 4-14.) The value of E_{bb} is su that the cutoff potential E_{co} is minus 7 vol The maximum amplitude of the input voltage 4 volts; thus the grid voltage ((C) of fig. 4- swings in a positive direction from minus volts to minus 1 volt and in a negative direct from minus 5 volts to minus 9 volts. During time that the grid voltage remains below cut the plate current remains at zero and the pl voltage is held at the level of E_{bb}.

A combination of grid limiting and cu limiting may be employed in an amplifier c cuit to produce a square wave from a sine wa

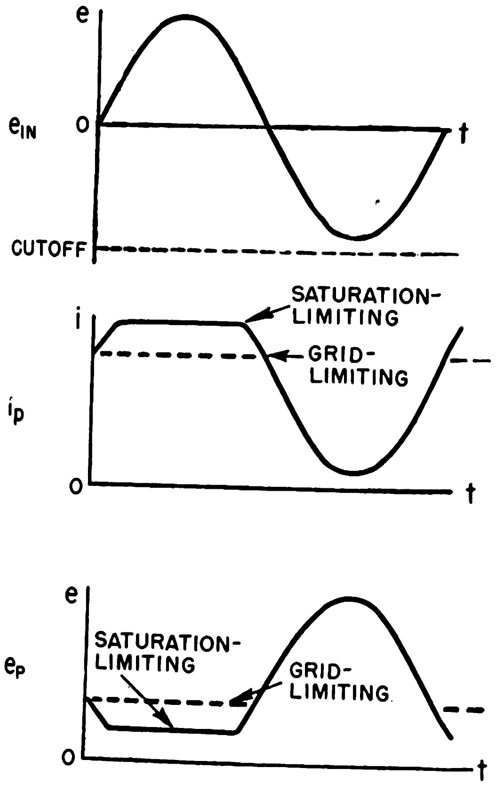

Figure 4-13.—Comparison of grid and saturation limiting.

(See fig. 4-15.) The amplitude of the input voltage is sufficiently high to hold the grid beyond cutoff for the greater part of the negative swing. The grid resistor R is on the order of 1-megohm and limits the grid voltage essentially to zero during the positive swing.

The Overdriven Amplifier

An amplifier circuit in which SATURATION LIMITING is employed in conjunction with CUTOFF LIMITING to produce a rectangular wave from a sine wave is generally known as an OVERDRIVEN AMPLIFIER. The driving circuit for such an amplifier should have a relatively low-output impedance and be capable of delivering power since considerable current is drawn during the positive swing of the grid. The value of the load resistor R_L is made as large as practical for the plate-voltage supply available.

Figure 4-16 illustrates the grid-voltage, plate-current, and plate-voltage relationships as determined by the i_p vs. e_p characteristics and the circuit constants of the overdriven amplifier.

TYPICAL APPLICATION OF LIMITERS

The Squarer and Peaker Circuit

The squarer and peaker circuit uses the principles discussed in the preceding limiter circuits. Each part of this circuit is used in several electronic circuits, and the entire circuit is used in some radar sets.

Notice the simple squarer and peaker circuit in (A) of figure 4-17. The first tube is an overdriven amplifier which squares the input sine waveshape and amplifies it according to principles of triode limiting. The 0.002-μf. capacitor and 500-K resistor form a short time-constant combination which peaks the square wave. The grid of the second triode is biased so that only a positive or negative amplified peak appears in the output. Because of this limiting action, it is called a limiter or clipper stage.

Circuit Analysis

In analyzing the peaker circuit, first inspect the circuit diagram. The first stage is a triode which looks like an amplifier stage except that it is not biased. However, there is a 1-megohm grid-limiting resistor in its grid circuit. This stage applies its output through capacitive coupling to the second triode, a stage which uses a 100-K load resistor and fixed bias of 50 volts. Bias in this stage is provided by a 250-K and 50-K voltage divider across the positive 300-volt supply.

Now consider the operation of the peaker. As the input voltage goes from zero to a positive voltage, the grid of the first triode is made positive with respect to its cathode. Immediately, grid current flows through the cathode-to-grid resistance of the tube and the 1-megohm resistor. The internal resistance of the cathode-to-grid path is less than a thousand ohms; therefore, the voltage developed by grid current divides at a ratio of 1,000 to 1 across the tube and the plate-load resistor. At the positive peak of the input voltage peak (163 volts), the grid voltage is about a tenth of a volt. The grid

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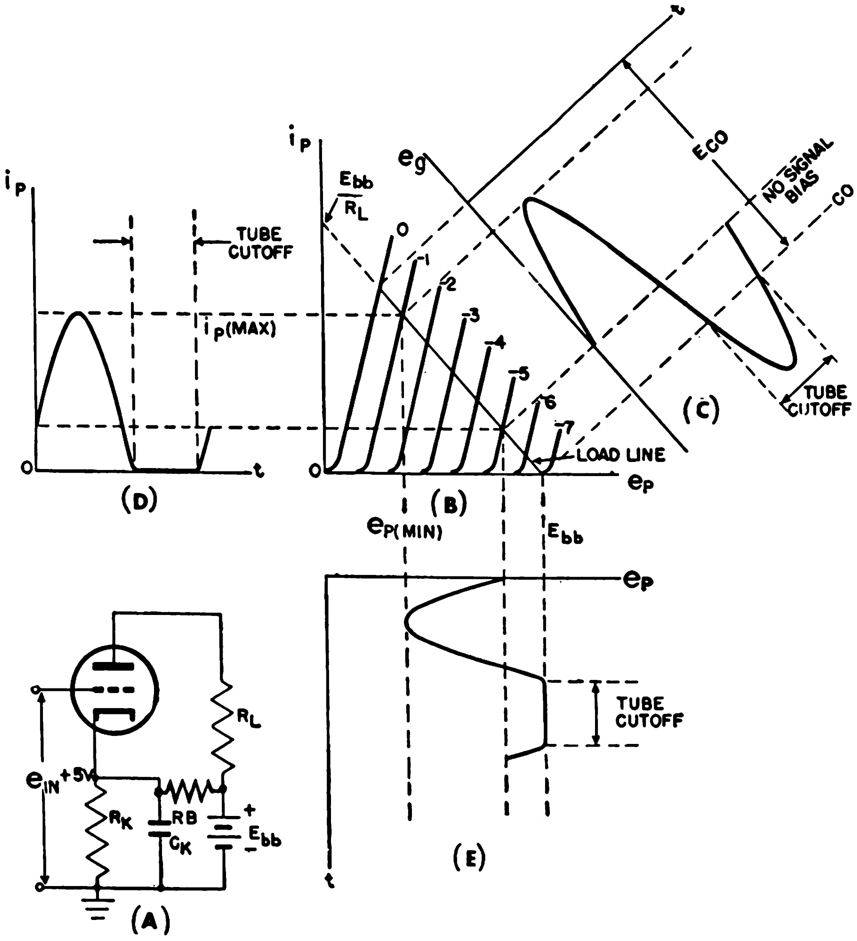

Figure 4-14.—Squaring top of plate voltage by cutoff limiting.

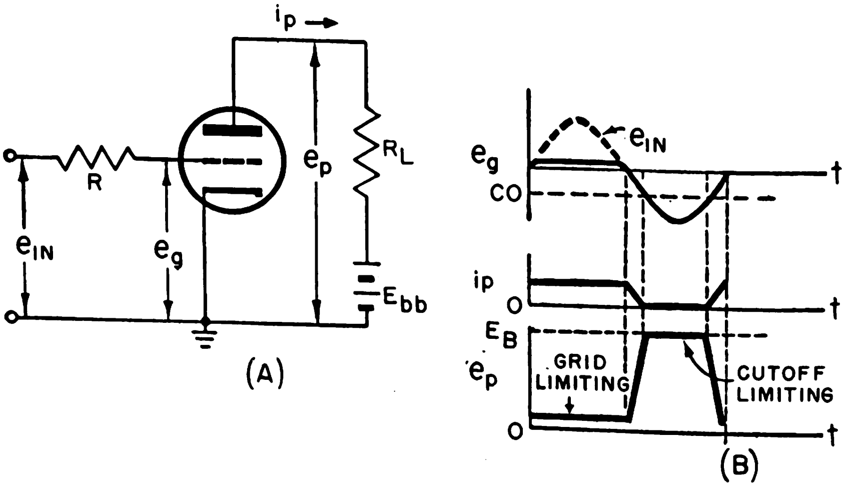

Figure 4-15.—Formation of a square wave by grid and cutoff limiting.

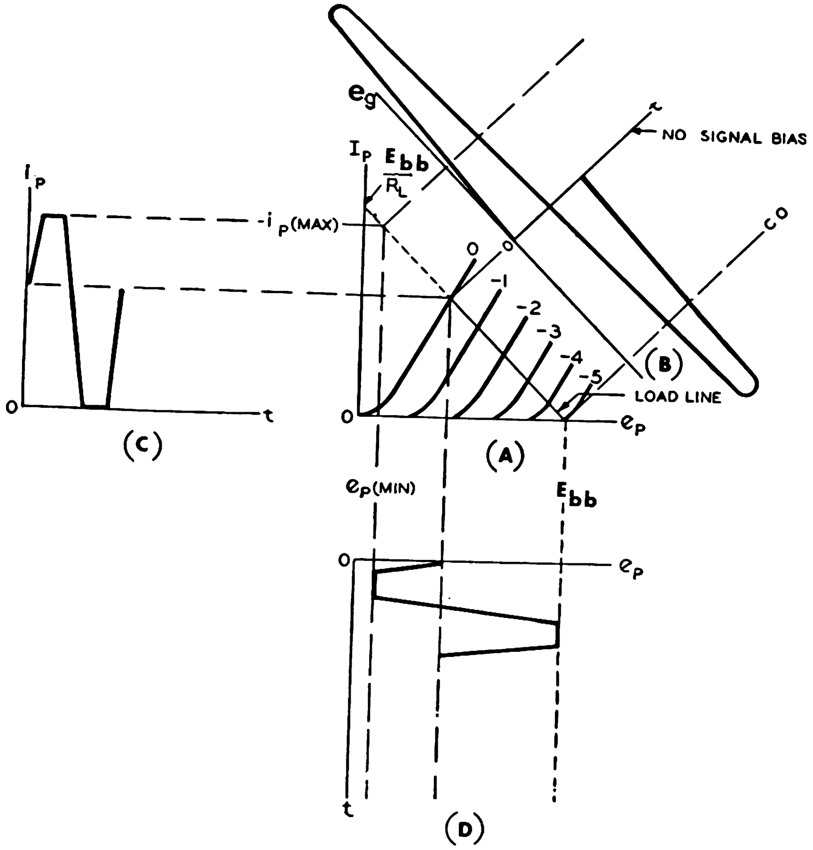

Figure 4-16.—Formation of a square wave by saturation and cutoff limiting.

waveshape shows this voltage as a flat line at the zero level. (The dotted line is the applied voltage; the solid line is the actual grid voltage.) The plate voltage of the first triode during this time is rather low because the plate current is unlimited by the grid. To determine its exact value, construct a loadline on the characteristic curves as follows: First, calculate the maximum current by dividing the plate supply of 300 volts by the load resistance of 50K. Thus, the maximum current is 300/50K, or 6 ma. Draw a line across the curves from the 300-volt zero current point on the bottom to the 6 ma. zero voltage point along the current scale. This line is the loadline.

The first use of the loadline is to find the plate voltage for zero grid voltage. At the intersection of the zero grid-voltage curve and the loadline, drop down to the plate-voltage scale at the bottom. The point shows that the plate voltage is 55 volts. During the positive swing of applied voltage, the grid actually goes slightly positive. This is shown by the exaggerated curve of the plate-voltage change which is shown at (E) of the figure. At the start of the half cycle, the curve is at 55 volts, but drops below that slightly as the grid goes slightly positive, then returns to 55 volts at the end of the half cycle.

Next, consider the input voltage during the negative half cycle. First, however, remember that the grid does not draw current when it is negative. Therefore, when no current flows through the 1-megohm resistor, there will be no voltage drop across it. Thus, the full input voltage will appear at the grid during the entire negative half cycle as it is shown in the grid-voltage curve at (D). On glancing at the loadline, notice that it crosses the zero current axis at the end of the minus 17-volt grid curve. Thus, when the grid voltage reaches minus 17 volts, the plate current will have decreased to zero. The grid curves show that this value is reached very quickly during the negative half cycle. The grid voltage continues to swing with the applied

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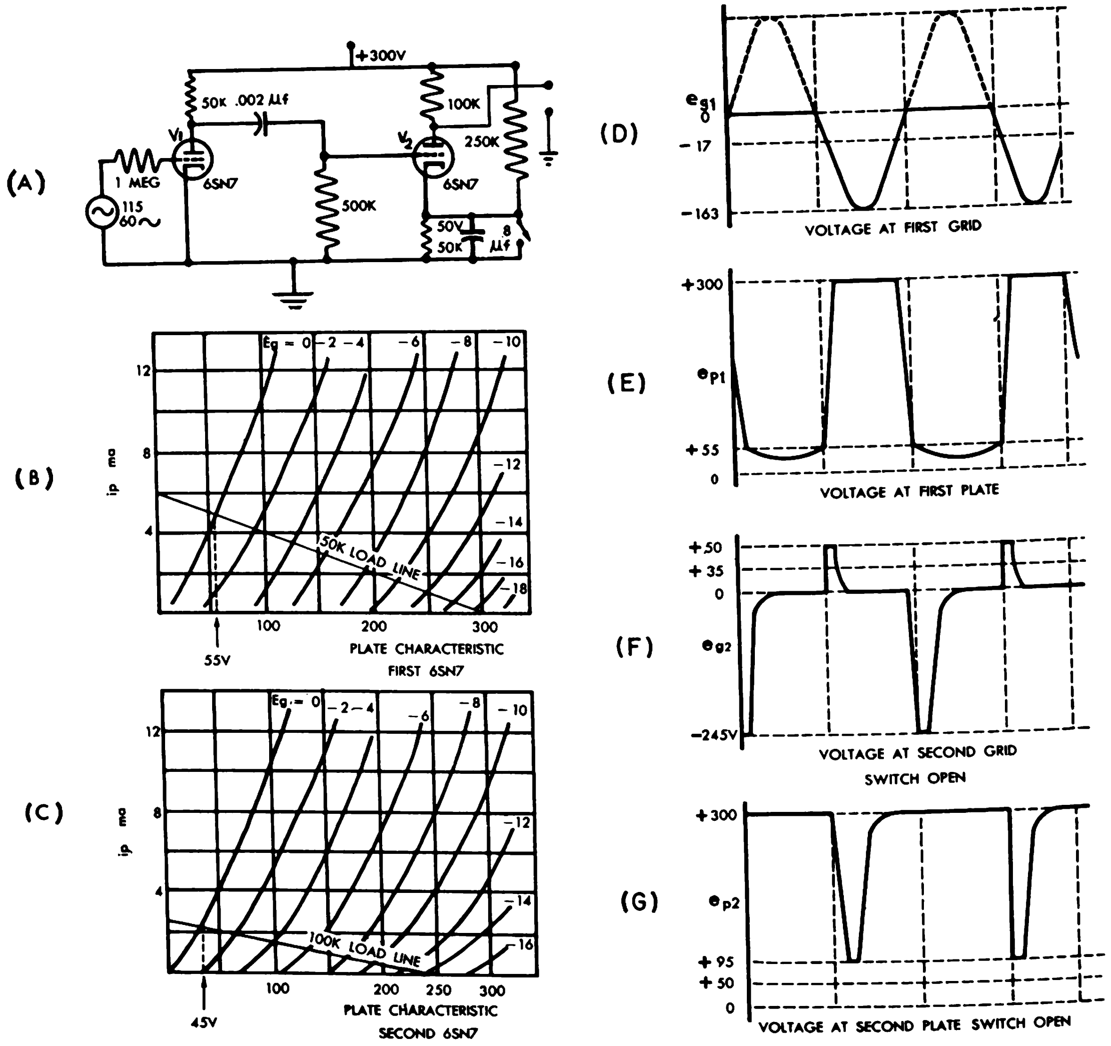

Figure 4-17.—Squarer and peaker circuit.

voltage through minus 163 and back to zero. All this time the grid voltage is more than 17 volts negative, and the plate current remains at zero. As the grid voltage starts to become negative, the decrease of current through the 50-K load resistor causes the plate voltage to increase toward the 300-volt supply voltage. The change is very rapid because the grid voltage crosses the cutoff value in less than 1/100 of the cycle. Therefore, the plate voltage rises to plus 300 volts during the entire time the grid voltage is below the cutoff value on the curve. As it comes above cutoff, the plate voltage again drops to 55 volts. And again, the grid-voltage change from minus 17 to zero is very steep, and accordingly the plate-voltage change is exceedingly fast. The long period of time that the grid is below cutoff and the rapid changes cause a square wave to be developed at the plate of the first triode.

The square-wave output of the first stage is applied to an RC circuit consisting of the 0.002-μf. capacitor and 500-K resistor in the grid of the second tube. The voltage across the resistor becomes the grid voltage. At the start of the first half cycle the square wave is negative. Since the capacitor is initially uncharged, the application of this negative-going voltage to it immediately causes current to flow through the RC circuit. With no drop across the uncharged capacitor, the full voltage appears across the resistor. The third curve at (F), labeled e_{g2}, shows the entire voltage chang occurring at the second grid.

Suppose for the moment you examine the conditions in the second tube when this grid voltage is applied to it. The cathode is 50 volts positive with respect to ground. The actual plate voltage is 300 minus the 50 volts on the cathode, or 250 volts. Notice the loadline on the lower set of characteristic curves. This line is drawn from the 250-volt supply-voltage zero current point to the 250/100K, or 2.5 ma. zero voltage point. On referring to this line, notice that the plate current becomes zero when the grid voltage is minus 15 volts. With 50 volts bias on this tube, there will be no current until more than plus 35 volts is applied to the grid. Therefore, the negative swing of 245 volts applied to the grid will not change the plate current from its zero value. But also note that this waveshape is not like the square wave applied because the RC time constant is short. The total time the voltage is applied is 1/120 or 0.00833 second, while the RC is 0.002 μf. x 0.5 megohm or 0.001 second, a ratio of about 8 to 1. In other words the capacitor is small and becomes charged during the very first portion of the square wave. As it becomes charged, the current through the 500-K resistor becomes lower and lower until after 5 time constants or 0.005 second, it drops to zero. The resistor voltage stays in step with this decreasing current so the voltage drops exponentially to zero. The grid voltage stays at zero for the duration of the half cycle or until the reversal of the square wave occurs.

At the end of the first half cycle the voltage at the first triode changes 245 volts in the positive direction. Again this change immediately appears across the resistor. Nothing happens, however, until the voltage reaches 35 volts. Then current starts to flow in the tube. As the voltage increases from 35 volts to 50 volts, the actual grid-to-cathode voltage at the second tube rises from minus 15 volts to zero. Now the plate waveshape at (G) for this second tube can be examined. During the entire previous half cycle, the tube was at cutoff and the plate voltage remained at plus 300 volts. But now current is flowing, and the voltage drops to that value of plate voltage for zero grid voltage. This value can be determined again from the loadline. Find the intersection of the zero grid voltage line with the loadline and proceed downward to the plate-voltage scale. It reads 45 volts in this curve. This might seem inconsistent inasmuch as the plate-voltage curve in (C) of figure 4-17 indicates that the plate voltage is 95 volts. But remember that the voltage is being indicated with respect to ground. Therefore, the 45 volts across the tube must be added to the bias voltage to obtain the total voltage from plate to ground. Now return to the second grid. As the square wave gets above 50 volts, the grid becomes positive and starts to draw current. So you see that the positive-going voltage on the second grid levels off at zero. Only a small part of the remaining voltage rise of 245 volts ever appears across the grid to cathode. This is due to the fact that the grid current flows through the 0.002-μf. capacitor and 50-K load resistor, and this combination of the 50-K resistor and the high reactance of the small capacitor acts as a grid limiter to divide the total voltage. The small grid-to-cathode resistance of about 500 ohms will have a very small voltage drop across it. The 500-K resistor is still in the circuit but so much of the current flows through the grid itself that the 500-K resistor can be practically disregarded during this time. The low resistance and small capacitor form a very short RC circuit, so the capacitor will be charged quickly. The voltage at the grid then drops back to zero with respect to ground which is 50 volts negative with respect to the cathode. So the triode conducts only during the brief period of time that the grid is above cutoff. The plate voltage stays at plus 300 volts most of the time. A negative pulse is thus generated for each cycle of the original input sine wave. Its amplitude is 300 minus 95 or 205 volts.

When the switch in this circuit is closed, the circuit will generate a positive pulse for each cycle of the sinewave input. As shown in figure 4-18, when the switch is closed in the actual circuit, it shorts out the 50-K bias resistor and its parallel capacitor, and connects the 300-K resistor to ground. These three circuit elements become ineffective and an equivalent circuit may be drawn by omitting these elements. Now there is no bias on the second triode, and the full 300-volt supply voltage appears across the tube and its load resistor. To evaluate the current and voltages, it is necessary to draw a new loadline as shown in the characteristic curves. This line extends from the 300-volt zero current point at the bottom to the 300/100K or the 3 ma. zero voltage point at the side. With no bias, the grid voltage is zero, and the plate voltage under this condition is 40 volts.

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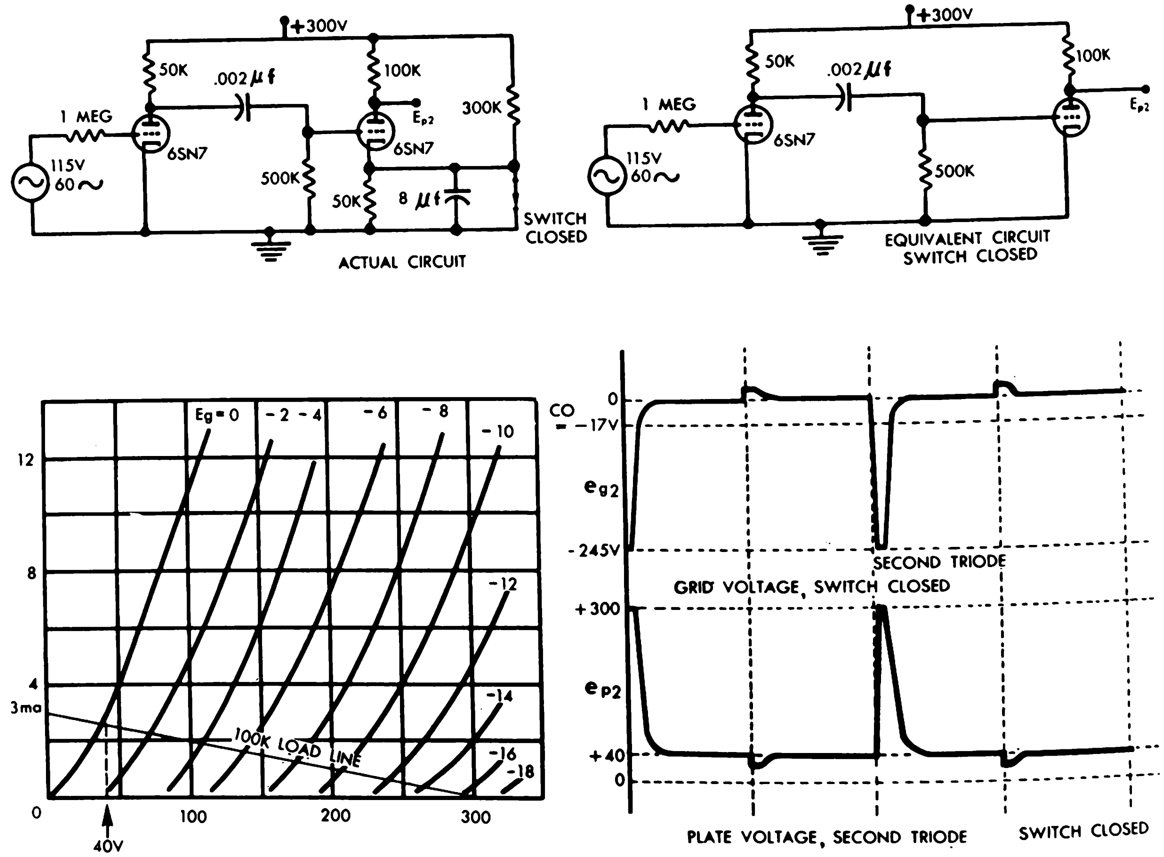

Figure 4-18. Squarer and peaker with switch closed to form negative peak.

On the negative half cycles the square wave will be peaked in the same manner as before. But on the positive peaks, grid current flow occurs at zero instead of the plus 50 volts as before. Similarly, as in the previous case, the high impedance circuit of the 0.002-μf. capacitor and 50-K load resistor prevents the grid from getting more than a fraction of a volt positive during positive half cycle.

The grid remains at zero value except when the input voltage is negative-going. Therefore, at zero grid voltage the plate current being high, the plate voltage which varies inversely with the plate current remains at a constant value of 40 volts. At the close of the first half cycle, the voltage is negative-going. Here the grid voltage changes rapidly from zero to the cutoff value, and the plate voltage rises sharply f 40 volts to plus 300 volts. The grid volt becomes negative by 245 volts, and the resul plate voltage levels off at the supply-volt level of 300 volts. However, the rapid cha of the 0.002-μf. capacitor causes the voltage to rise immediately to the cutoff v and beyond. As the grid voltage continues to to zero, the plate voltage drops back to 40 v If you study the plate-voltage waveshape, notice the fairly constant low plate voltage positive peaks with each cycle of input volt The positive peak voltage at the second only raises the grid a fraction of a volt a zero, thus causing the plate voltage to dip sli at each of these points. Thus, with this ci it is possible to obtain either positive or n tive peaked pulses by the flip of the switch

Direct-Current Restorers or Clampers

A circuit which holds either amplitude extreme of a waveform to a given reference level of potential is called a CLAMPING CIRCUIT. The terms D-C RESTORER and BASELINE STABILIZER also are commonly used. Such circuits are divided roughly into two classifications. The first, DIODE AND GRID CLAMPING, clamps EITHER amplitude extreme and allows the waveform to extend in only one direction from the reference potential. The second, SYNCHRONIZED CLAMPING, maintains the output potential at a fixed level until a synchronizing pulse is applied, at which time the output potential is allowed to follow the input. At the end of the synchronizing pulse the output voltage is returned immediately to the reference level.

To demonstrate the utility of clamping circuits, a brief review of the action of coupling networks is useful. In coupling between stages in electronic circuits a coupling capacitor almost always must be used to keep the high positive d-c plate potential of the first tube isolated from the grid of the second tube. It is desirable that only the VARYING component of the plate potential be transmitted to the grid as a signal varying above and below some fixed reference level. If the lower end of the grid-leak resistor is grounded, the signal varies above and below ground. If a biasing potential is employed, the signal applied to the grid varies above and below this d-c bias voltage.

In class A operation, the latter condition is desirable. The biasing potential is adjusted to the center of the class A range and the varying potential is kept within the limits of this range. The center of the grid swing is fixed, and the amplitude variation of the grid voltage directly affects the amplitude of the plate-voltage swing. This is exactly the condition desired in class A operation (fig. 4-19 (A)).

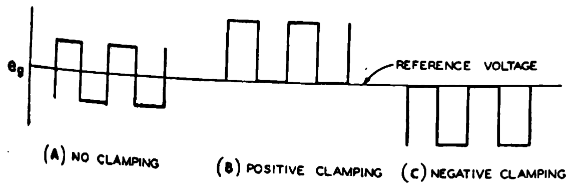

Figure 4-19.—Grid voltage variation with respect to definite reference potential.

In other circuits, however, the waveform swing must be entirely above or entirely below the reference voltage, instead of alternating on both sides of it. (fig. 4-19 (B) and (C)). For these applications a clamping circuit is used to hold either the positive extreme or the negative extreme of the waveform to the desired level.

The output of an ordinary RC coupling network is alternating in character, swinging about the average voltage level of the applied waveform. After the coupling capacitor charges to the average applied voltage, any decrease in applied voltage causes the output voltage of the RC network to swing negative. Any increase above the average causes the output voltage to swing positive. Now if the capacitor can be made to charge, say to the MINIMUM applied voltage and no more, any swing has to be in the positive direction. The output voltage varies between zero and some positive value, depending on the amplitude of the input signal. If, on the other hand, the capacitor can be made to charge to the MAXIMUM applied voltage and remain charged to that level, any swing necessarily is in the negative direction. The output voltage varies between zero and some negative value, depending on the amplitude of the input signal. In the first case the bottom of the output waveform is clamped to zero (fig. 4-19 (B)), and in the second case the top of the output waveform is clamped to zero (fig. 4-19 (C)).

POSITIVE AND NEGATIVE DIODE CLAMPERS

The simplest type of clamping circuit utilizes a diode in conjunction with the ordinary RC coupling circuit. Consider the case in which the capacitor voltage is maintained at the minimum applied voltage (fig. 4-20). In order to understand the action of this circuit, the following significant point should be kept in mind: If the cathode of a diode is made negative with respect to the plate, or the plate positive with respect to the cathode, electrons flow from cathode to plate and the tube constitutes a low resistance. On the other hand, if the cathode is made positive with respect to the plate or the plate negative with respect to the cathode, no current flows and the tube may be considered an open circuit.

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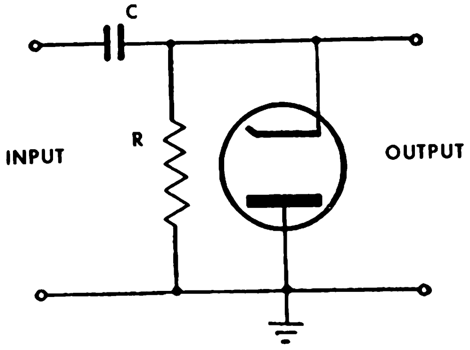

Figure 4-20.—Positive clamping circuit.

The plate-voltage variation of a circuit producing a square-wave output (fig. 4-21) is typical of the kind of input applied to the clamping circuit of figure 4-20. In this clamping circuit, capacitor C charges gradually through the high resistance R. After a period of time, depending on the RC time constant, the charge on the capacitor reaches 50 volts, the base of the input waveform. The problem is to maintain the charge at this value in spite of the tendency of the capacitor to charge to a higher level when the applied voltage goes to plus 150 volts.

Assuming that a steady voltage equal in magnitude to that at point A in figure 4-21 has been applied for some time, the capacitor in figure 4-20 may be considered as being charged to 50 volts. During the time between A and B the charge on the capacitor is equal to the applied voltage and no current flows. Then at point B the applied potential suddenly increases to plus 150 volts. Since it is impossible for the charge on the capacitor to change instantaneously, the difference between the plus 150 volts applied and the 50 volts across the capacitor must appear across R. The difference of 100 volts becomes the output voltage. Note that e_R is the output voltage.

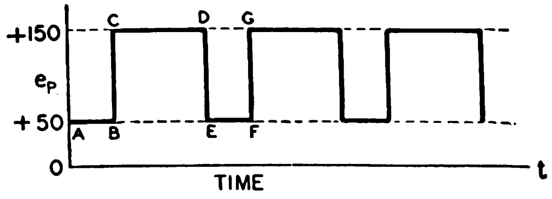

Figure 4-21.—Typical plate voltage applied to clamping circuit.

The fact that a voltage appears across R (fig. 4-20) indicates that a current is flowing through it. This current flow adds to the charge on C. Ordinarily the RC time constant would be very long and the actual charge added to C would be extremely small. For simplicity, assume that the 150-volt potential is applied for a time equal to 1/10 RC or from point C to point D. Since the cathode of the diode is positive with respect to the anode, the tube is in effect an open circuit and R is a high resistance. During a time equal to 1/10 RC the charge on the capacitor increases exponentially by 10 percent of 100 volts, or 10 volts, making the total charge 60 volts. During the same time the drop across the resistor decreases exponentially by 10 volts to a value of 90 volts, leaving the sum of e_r and e_c still equal to the applied potential of 150 volts.

Now at point D, the applied voltage suddenly drops back to 50 volts, but the capacitor is charged to 60 volts. This would leave an output voltage across R of 10 volts negative with respect to ground—a condition it is hoped to avoid. In order for the output to return to zero very quickly, the capacitor must discharge the extra 10 volts through a very short RC path.

In figure 4-20 the cathode of the diode is connected to the high side of R and the plate is grounded. Any output voltage which is negative with respect to ground makes the cathode negative with respect to the plate. In this state the diode conducts and becomes, in effect, a very low-resistance discharge path for the capacitor until the charge is again equal to the applied voltage and the output voltage returns to zero. These conditions are illustrated in figure 4-22.

To illustrate the operation of the positive-clamping circuit further, it is assumed that the waveform shown in figure 4-23 is applied to the clamping circuit of figure 4-20. Since at point A the input voltage is zero, the output voltage is zero and remains so until point B is reached. At this time the input voltage drops suddenly to minus 100 volts at point C. Since the capacitor cannot change its charge instantaneously, the output voltage across R also drops suddenly to minus 100 volts. Since the cathode of the diode is 100 volts negative with respect to the plate, the tube conducts heavily, charging the capacitor very rapidly through a short RC until the capacitor voltage becomes equal to the applied voltage. At this time the output voltage has returned to zero and the diode becomes nonconducting. As long as the input remains at

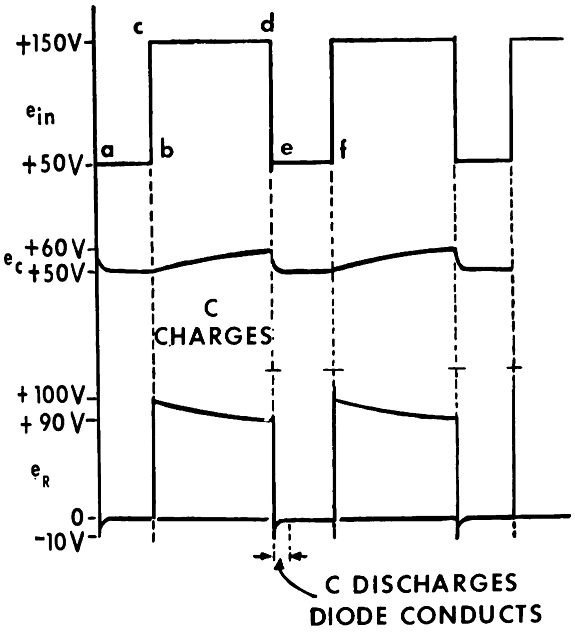

Figure 4-22.—Waveforms e_c and e_r of diode-clamping circuit with grounded plate for input signal e_{in}.

minus 100 volts, from point C to point D, the output voltage remains at zero potential.

At point D, the input voltage changes back to zero, a rise of 100 volts in the positive direction (minus 100 to 0). This rise produces a rise of 100 volts (0 to plus 100) across R, as the capacitor again cannot change its charge instantaneously. The capacitor must now discharge very slowly as the diode is nonconducting and the high-resistance path through R must be utilized.

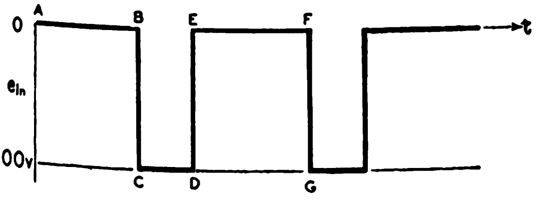

Figure 4-23.—Typical voltage applied to diode-clamping circuit.

Assuming again a time for discharge from points E to F of 1/10 RC, the voltage across the capacitor at F, and thus the output voltage, decreases to 90 volts, since the input is zero. At point F the input signal again drops to minus 100 volts. Instantaneously the output across R goes to minus 10 volts (input minus e_C). The diode conducts quickly, returning the charge on the capacitor to 100 volts and the output to zero. These results are shown in figure 4-24. Note that no portion of the waveform is lost after the first cycle. The function of the clamping circuit is merely to shift the reference voltage from the top of the waveform to the bottom.

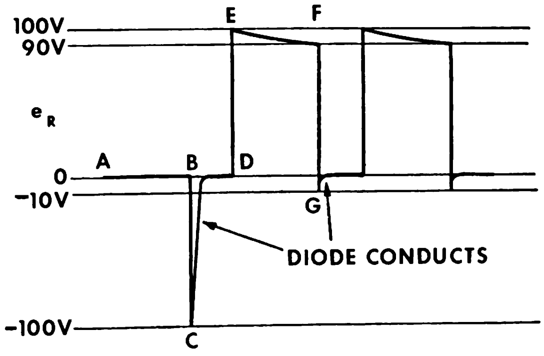

Figure 4-24.—Output waveform of diode-clamping circuit with grounded plate and input signal as shown in figure 4-23.

Figure 4-25 illustrates a diode-clamping circuit capable of causing the output waveform to vary between some negative value and the zero reference voltage. The only difference between this circuit and the one shown in figure 4-20 is in the manner in which the diode is connected. In this case the plate is connected to the output terminal while the cathode is grounded. Therefore in this condition the tube conducts whenever the plate rises above ground.

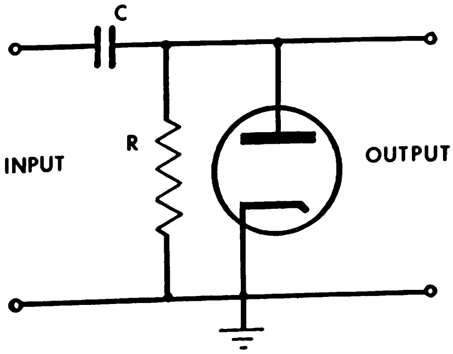

Figure 4-25.—Negative-clamping circuit.

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The input signal (fig. 4-21) is now applied to this negative-clamping circuit. When the input is at point A, the plate of the diode becomes positive and the capacitor quickly charges up to plus 50 volts through the short RC path. When this occurs the output voltage drops to zero. Then at point B the input voltage suddenly rises 100 volts (from plus 50 volts to plus 150 volts). Since the capacitor charge cannot change instantaneously, the 100-volt change appears across R, sending the plate of the diode to plus 100 volts with respect to the cathode. The capacitor again is presented with a short RC charging path and charges very rapidly, bringing the output voltage back to zero quickly. At point D the input signal suddenly drops 100 volts, but capacitor C is charged to 150 volts and cannot change instantaneously. The 100-volt drop therefore appears across R, sending the output from zero to minus 100 volts. The input voltage drops from plus 150 volts to plus 50 volts and the output drops from 0 volts to minus 100 volts. During the time from E to F the capacitor can be expected to discharge a small amount through the high-resistance path of R. At point G this slight loss of charge is replaced quickly as the plate of the diode goes positive momentarily. The output signal is shown in figure 4-26.

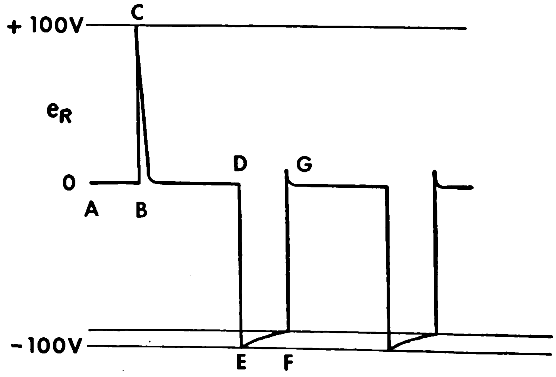

Figure 4-26.—Output waveform of diode-clamping circuit with grounded cathode and input signal as shown in figure 4-21.

In the practical circuit the size of the resistance R is great enough to make negligible the amount of distortion of the output caused by the slight charging of the capacitor.

Grid Clamping

The function of clamping may be performed at the grid of an ordinary triode or pentode as well as in a diode. Any element of a vacuum tube, if made positive with respect to the cathode, attracts electrons from it. On the other hand, any element made negative with respect to the cathode repels electrons and has no current flow. Thus the grid of a tube connected as shown in figure 4-27, acts as the plate of a diode and produces the same clamping action as the circuit of figure 4-25. Any tendency for the grid to go positive causes grid current to flow, charging capacitor C to the applied potential.

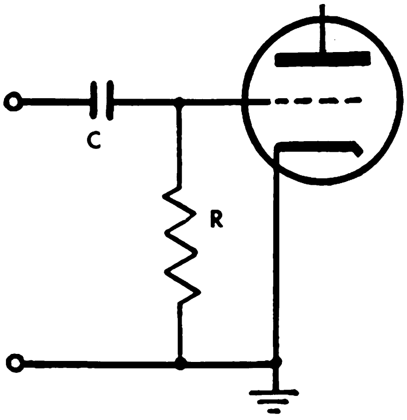

Figure 4-27.—Grid-clamping circuit.

Clamping Above or Below Ground Potential

Although circuits previously discussed clamped one extreme of the input signal to zero potential, actual circuits need not be limited to this one reference potential. Figure 4-28 illustrates the means of clamping the upper extreme of an input signal to minus 10 volts with respect to ground. The same principle may be applied to clamp either voltage extreme to any reference potential.

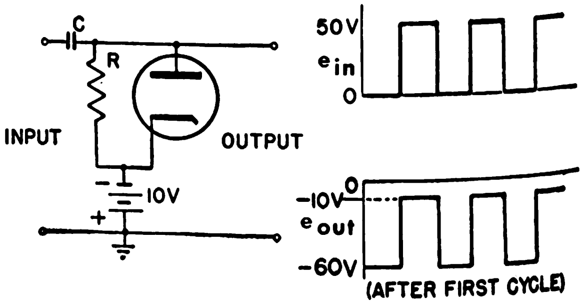

Figure 4-28.—Clamping circuit which establishes reference potential of minus 10 volts.

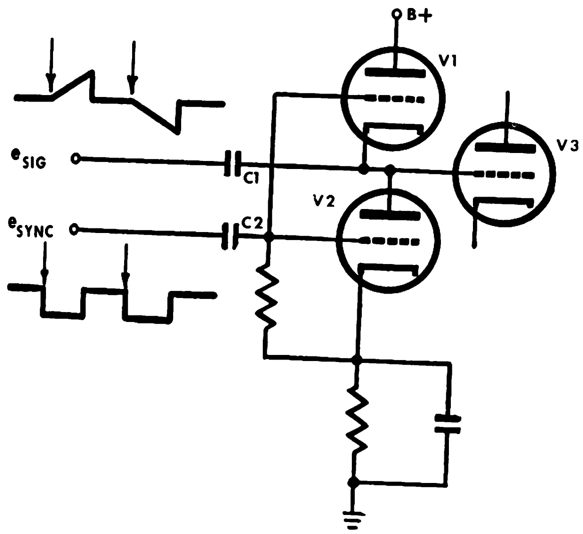

Figure 4-29. —Synchronized clamping circuit.

SYNCHRONIZED CLAMPING

A more versatile clamping circuit is shown in figure 4-29. This arrangement keeps the bias on V_3 constant except for the time during which the clamping tubes V_1 and V_2 are held beyond cutoff by a synchronizing pulse. During the period of conduction of V_1 and V_2, these tubes may be considered as part of a voltage-divider network for the purpose of placing a definite voltage on the grid of V_3. Actually the circuit is slightly more complicated than the simple voltage-divider explanation would imply.

In figure 4-29, while V_2 is operating at zero (grid-to-cathode) bias and may be considered therefore as a simple resistor, V_1 is biased by the drop across V_2. The reason is that the cathode of V_1 is connected directly to the plate of V_2 and the grid of V_1 is tied directly to the grid of V_2, which in turn is connected effectively to the cathode of V_2, so long as no synchronizing potential is applied.

Assume that for some reason the potential at the grid of V_3 tries to rise. The voltage at the grid of V_3 and the voltage across V_2 are identical. Thus a rise in the grid voltage of V_3 results in an increase in the bias on V_1, which makes it a higher resistance than before, bringing the voltage at the plate of V_2 back to normal. In like manner a decrease in the voltage at the grid of V_3 means a decrease in the bias of V_1, which decreases the resistance of V_1, bringing the voltage at the grid of V_3 back to normal. As long as V_1 and V_2 conduct, the voltage at the grid of V_3, and thus the plate current of V_3, are held constant by the voltage-divider action of V_1 and V_2. V_1 is the variable resistance which controls the fraction of the B-plus voltage that appears across V_2.

The synchronizing pulse is applied as a negative rectangular wave which drives V_1 and V_2 beyond cutoff for the desired length of time. With tubes V_1 and V_2 cut off, the grid of V_3 is left free to follow any changes in input-voltage amplitude. Capacitor C_1 has no path through which to discharge except by way of the very high resistance of the insulating material used for tube bases and sockets. Thus the voltage at the grid of V_3 follows exactly the input voltage. At the end of the synchronizing pulse V_1 and V_2 again conduct, returning the voltage at the grid of V_3 quickly back to the reference potential.

APPLICATION OF CLAMPING CIRCUITS

In equipment employing cathode-ray tubes, clamping usually is encountered in the sweep circuits. If the sweep voltages do not always start from the same reference point, the trace itself does not begin at the same point on the screen each time the cycle is repeated, and is therefore jittery or erratic. If a clamping circuit is placed in the grid circuit of the final sweep amplifier, the voltage from which the sweep signal starts can be regulated by adjusting the d-c voltage applied to the clamping circuit. An arrangement such as that shown in figure 4-28 insures, in the case of a negative-going sweep voltage, that the waveform applied to the deflection plate varies in a negative direction from the d-c voltage level applied to the cathode of the diode.

A typical radar PPI (Plan Position Indicator) deflection amplifier that uses the synchronized clamping circuit just discussed is shown in figure 4-30. The equipment makes use of four deflection amplifiers (two vertical and two horizontal). A dual triode clamping tube is used with each deflection amplifier. Figure 4-30 shows only one clamping and one deflection amplifier. The other three circuits are identical with this one. Notice in figure 4-30 how the cathode resistor of the clamping tube V209A is now a variable resistor R253. The resistor is used to center the start of the PPI sweep vertically. A similar adjustment for horizontal

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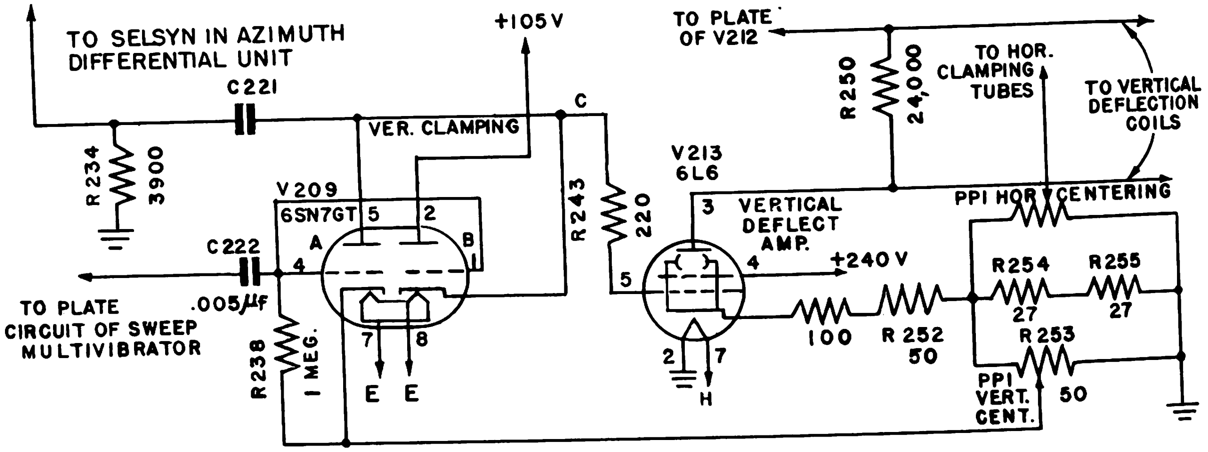

Figure 4-30.—Clamping tube circuit.

centering is contained in the horizontal clamping circuits.

An application of these clamping circuits may be found in radar equipment where GROUND STABILIZATION is added to the system. Ground stabilization is used for the purpose of causing the start of the PPI sweep to be displaced. This displacement is governed by the speed and direction of the aircraft containing this radar equipment. One result of this action is that ground targets will remain in a fixed position on the scope. Secondly, all targets that are moving, such as ships or aircraft, will move across the scope in their true direction and at their true speed. This displacement of the start of the sweep is accomplished by varying the bias on the clamping tubes. The varying bias is derived from the auxiliary ground stabilization equipment.

Time Base Generators

A time base generator circuit is a circuit that generates the voltage which causes the spot to move across the CRT screen at a constant rate. The distance along the trace formed by the moving spot is the basis of establishing time intervals. When recurrent voltage changes are superimposed on the trace, it is possible to measure both time and frequency of a radio signal, and in radar to measure the distance of targets. Commercial test oscillographs employ a thyratron tube in the time base generator circuit because of the simple way in which the frequency can be changed. In radar sets the time base generator circuit usually employs a high-vacuum tube.

REVIEW OF THE THYRATRON SWEEP GENERATOR

The movement of the spot in a CRT may be caused either by a voltage change on the deflection plates or by a current change in the deflection coils. The chief requirement is that the voltage (or current) must change linearly with time.

Although both the R-C and L-R circuits consume time during a voltage change, the R-C circuit is the one usually preferred as a means of generating a changing voltage. As previously mentioned, an R-C circuit contains a series resistor, and a capacitor. When these parts are connected and a d-c voltage applied, the capacitor will start to charge; but since the resistor limits the current, the charge will not be instantaneous, but at a rate which is exponential. The charging curve is quite linear in the very beginning, and the capacitor charging process is usually stopped before the slope of the charging curve changes appreciably. After the charging stops, the capacitor discharges, and the events just described repeat and the capacitor recharges.

Most time base generators use this very same charging and discharging process. Any circuit differences that exist result largely from the methods employed for high-speed switching of the capacitor from charge to discharge. One device used for this switching action is the vacuum tube. The circuit in (A) of figure 4-31 shows a gas triode or thyratron, a special type of electron tube, employed for providing the necessary switching operation since this tube has certain special characteristics which make switching occur automatically. In the circuit the tube is in parallel with the capacitor. When the circuit is turned on, there is no charge on the capacitor and the tube acts like an open circuit due to the negative cutoff voltage on the control electrode, or grid. The capacitor charges along the first curve in (D) of figure 4-31. As the voltage increases, a potential is reached where the voltage across the tube is too high for the control electrode to keep the tube cut off and a small plate current starts to flow. This plate current ionizes the gas in the tube, and before the voltage can increase any further a sudden high plate current flows. The plate voltage for the tube is provided by the charged capacitor. Forcing a current through the tube causes discharge of the capacitor. Below a certain potential, the tube does not remain ionized, and when the capacitor is discharged down to this potential, the gas in the tube de-ionizes, and the grid regains control of plate current.

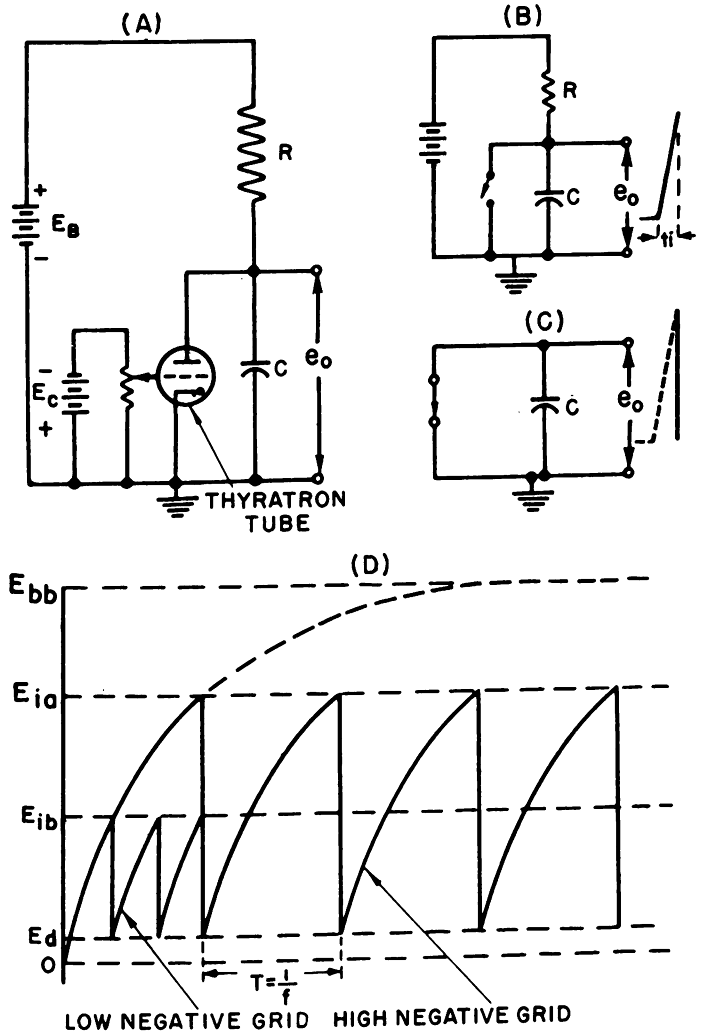

Figure 4-31.—Thyratron sweep generator.

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At this point it becomes an open circuit again and permits the capacitor to recharge. For further study refer to the equivalent circuits; the charge of the capacitor in (B) of figure 4-31 and the circuit during discharge in (C).

The curve for several charges and discharges in (D) of figure 4-31 shows that the voltage increases to the ionizing potential E_{ia} or E_{ib} and then drops very abruptly to E_d which is the de-ionizing potential. The slow rise is due to the size of R and C. The rapid drop in voltage forms an R-C curve, but the resistance of the ionized tube is so small that the capacitor is discharged almost immediately, causing the curve to be practically vertical. The voltage at which ionization occurs depends on the amount of voltage on the grid of the thyratron. If the grid is made less negative, a lower plate voltage will cause ionization. When ionization occurs earlier the amplitude of the waveshape may decrease on one hand, but on the other, since the discharge time is the same, the wave will repeat more often, that is, its frequency will become higher. Another result is that the charging curve is much more linear, that is, its slope is more constant.

Two facts of interest concerning thyratrons are that the de-ionization potential depends entirely on the gas pressure within the thyratron envelope and that de-ionization always occurs at the same potential regardless of the grid voltage or the applied plate potential. For example, the 884 tube, one customarily used in time base generator circuits, de-ionizes at about 20 volts.

The circuit which was described is called a free-running circuit; that is, so long as a d-c potential is applied, it continues to generate one time base after another. There are other circuits which are discussed later that must be driven. These generate only one time base and then wait for the driving voltage to start the charging process which generates the next time base.

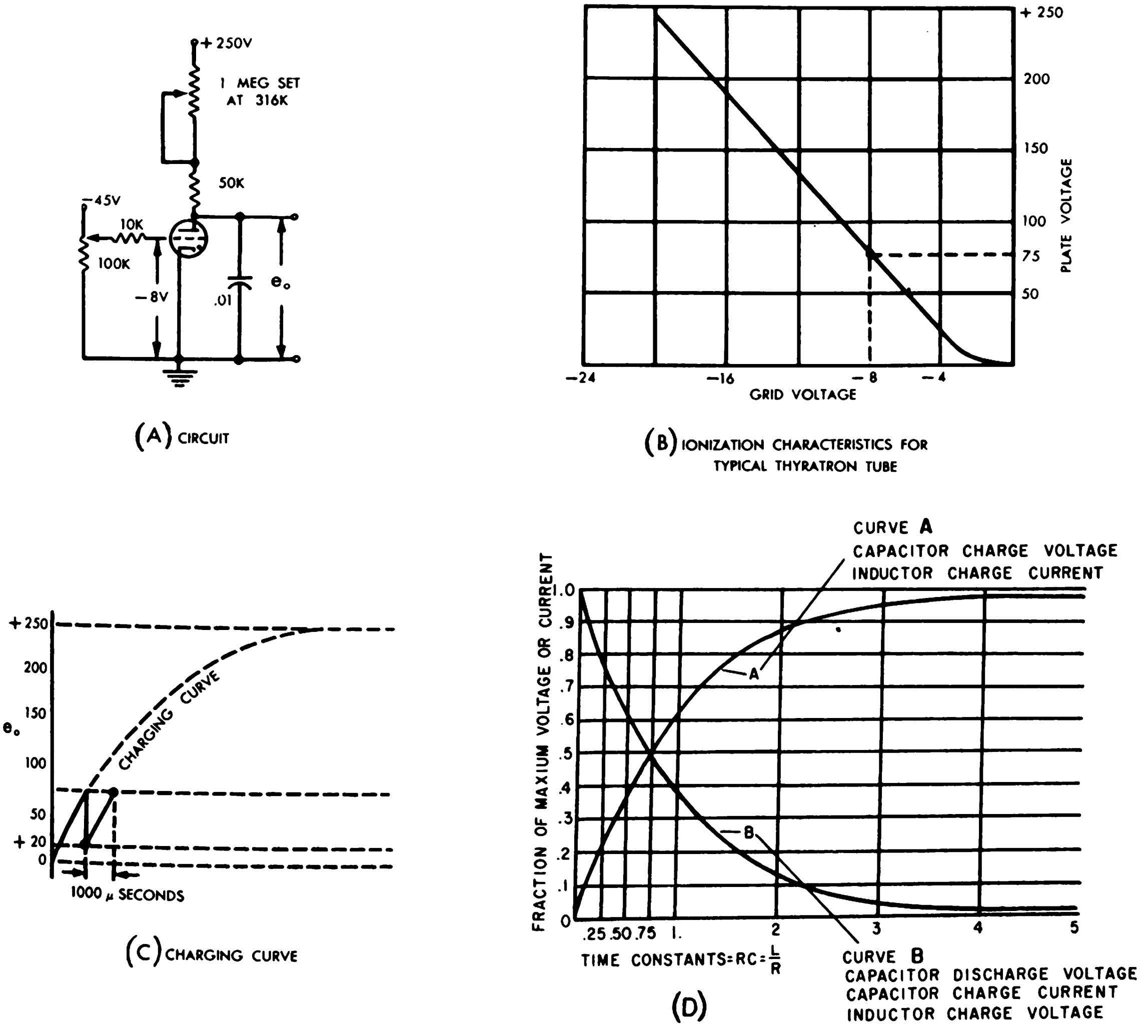
Determination of Operating Frequency

To calculate the frequency of oscillation of a thyratron sweep generator there are a number of factors that you must know. To become acquainted with these factors note figure 4-32 which shows a practical thyratron sweep-generator circuit. The applied voltage is 250 volts. The 50-K resistor in the plate circuit provides a minimum resistance in series with the tube. The 10-K resistor in the grid circuit limits the grid current to a safe value. To show how the operating frequency may be determined the following explanation is given. In this explanation it is assumed that the bias is set at minus 8 volts and the variable plate-load resistor is set at 316K, as shown in figure 4-32. The curve in (B) shows the relation of the firing potential to the grid bias. Thus, when the grid voltage is minus 8 volts, the tube ionizes when the plate-to-cathode voltage reaches 75 volts. Using this information, you can plot a charging curve like that shown in (C). This shows that during the first cycle the capacitor voltage starts from zero, but on the second and succeeding cycles it always starts charging from 20 volts, the de-ionization potential. At 75 volts, the thyratron ionizes, stopping the capacitor charge. With 230 volts applied, therefore, one cycle has a duration equal to the time required to charge the capacitor from 20 to 75 volts, or 55 volts.

To determine what fraction of full charge is represented by 55 volts, use the universal time constant chart curve (fig. 4-32 (D)). From it you learn that this value is 55/230, or 0.239. Therefore the capacitor is charged 23.9 percent before ionization. Using curve A in a universal time constant chart curve, find 0.239 of full charge, then move across to the curve, and down to 0.26 time constants. One time constant is RC, or 366K x 0.01, or 0.00366 second. Therefore, the time required for the charge is 0.26 x 0.00366, or 0.000952 second. Since frequency is the reciprocal of the time of one cycle, F = 1/0.000952, or 1,050 c.p.s.

To calculate frequency directly, use the following equations:

$$F = \frac{1}{2.302RC \log_{10} \frac{E_{bb} - E_d}{E_{bb} - E_i}}$$



(A) CIRCUIT

(B) IONIZATION CHARACTERISTICS FOR TYPICAL THYRATRON TUBE

(C) CHARGING CURVE

(D)

Figure 4-32.—Practical thyratron sweep-generator circuit.

Where,

F = Frequency in cycles per second.

2.302 = Logarithm conversion constant.

RC = Time constant.

E_{bb} = D-c applied voltage.

E_i = Ionization potential.

E_d = De-ionization potential.

$$F = \frac{1}{2.302 \times 3.66 \times 10^5 \times 10^{-8} \log_{10} \frac{250 - 20}{250 - 75}}$$

$$F = \frac{1}{8.4275 \times 10^{-3} \log_{10} 1.31}$$

$$F = \frac{1}{8.48 \times 10^{-3} \times 0.1186}$$

F = 1,000 c.p.s.

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Effect of Varying Circuit Components

Any variation in the circuit constants affects frequency, linearity, and amplitude. Thyratron time base generators used in commercial oscilloscopes are required to produce outputs which can be varied in frequency. In these sets coarse frequency changes are provided by means of switching capacitors, and fine frequency adjustment by means of varying the plate resistance and holding the grid bias constant. The usable frequency range extends from a few cycles to 50 kc. in the commercial oscilloscope. The upper frequency limit is 50 kc. because the discharge time at 50 kc. is equal to the charging time, and half of any signal being investigated will be lost during the flyback (discharge) time.

Synchronization

In addition to all the factors just mentioned, the temperature of the gas, the slightly variable ionization potential, and the load on the circuit also affect frequency. Because of these factors, the circuit is usually not stable enough to maintain an adequately constant frequency by itself and must be synchronized with an a-c voltage that has a constant frequency. This synchronizing voltage may be any voltage that has a frequency near (usually a little above) the multiple, sub-multiple, or fundamental frequency of the thyratron generator. Due to the synchronization voltage, the thyratron tube ionizes slightly ahead of normal time, and the capacitor discharges immediately and starts a

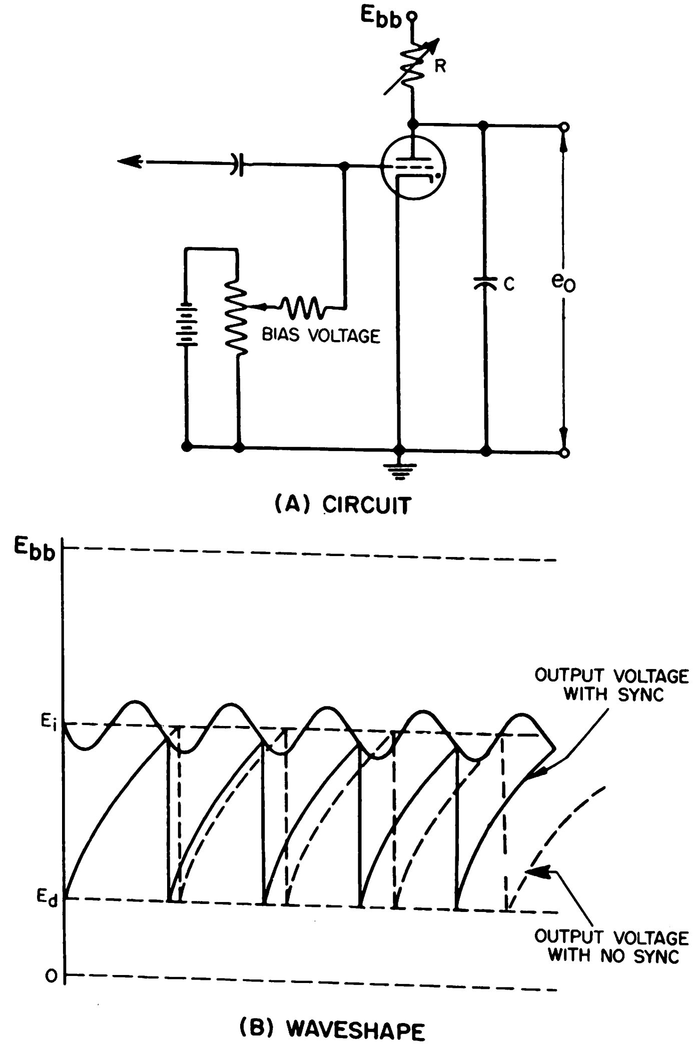

Figure 4-33.—Synchronization with sine wave.

new cycle. Diagram (A) of figure 4-33 shows a typical synchronization circuit in which a sine wave is used to synchronize the generator in the grid circuit. The sine wave varies the grid voltage and this in turn varies the ionization potential.

The waveshape in (B) shows how the ionization potential varies at a slightly higher frequency than the natural free-running frequency of the generator. The dotted sawtooth waveshape results from a constant ionization potential (no synchronizing signal). At the time the capacitor voltage is about to reach the normal value, the ionization potential drops. This drop is due to a synchronizing signal on the grid. When the capacitor voltage reaches the ionization potential, the ionization occurs, starting a new cycle immediately. The same action recurs with each cycle and causes the time base frequency to ''lock-in'' step with synchronizing frequency. Often, in the use of the commercial oscilloscope, the waveshape being displayed on the CRT is used for synchronization. This is done so that the waveshape and time base will occur simultaneously, and the pattern will be stationary. If there is no synchronization, a difference in frequency will exist and the pattern displayed on the screen will move forward or backward along the time base.

Typical Application of the Generator

A typical thyratron time base generator frequently used in oscilloscopes is shown in figure 4-34. The tube is a type 884 thyratron. Fixed bias is provided in the cathode by a voltage divider from B plus. The bias is held constant at 3.1 volts when the tube is nonconducting. Synchronizing voltage may be derived through a switch from one to three sources—the signal being displayed, the 60-cycle power line frequency, or from a terminal post to which any other signal can be connected. The 100-K potentiometer provides for varying the amplitude of the synchronization voltage applied to the grid. One of the eight capacitors when connected in the RC circuit provides for the coarse frequency adjustment. The 4-megohm potentiometer provides for fine tuning in that it can be used to set the frequency at exactly the desired value. Maximum linearity is obtained by keeping the amplitude of the output wave low. The desired amplitude is produced by amplifiers in stages that follow.

THE HARD-TUBE SWEEP GENERATOR

Because a thyratron is not readily adaptable for producing the time base with the spaced intervals required by radar and other electronic equipment, the high vacuum or hard tube is used instead. A hard tube is one that is highly evacuated; that is, one from which as much gas as possible is removed. In contrast, a SOFT tube is one with an incomplete vacuum; that is, one in which some gas remains in the envelope. A hard tube serves as a switch for discharging the capacitor but is not automatic and must be operated by an external circuit.

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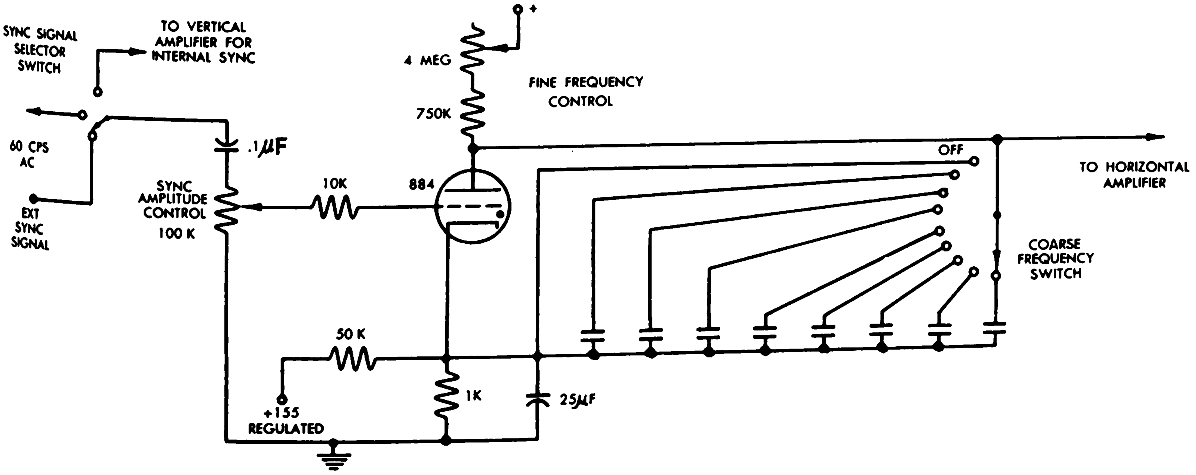
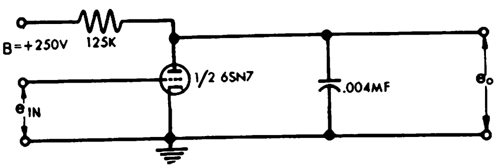


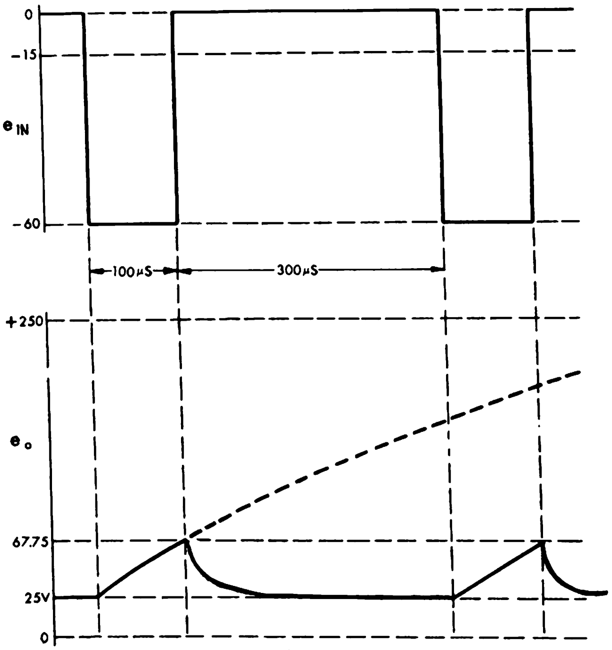
Figure 4-34.—A typical oscilloscope thyratron time base generator.

The circuit of a hard-tube sweep generator is shown in (A) of figure 4-35. In (B), the top waveshape shows the waveshape of the voltage that is usually used to operate the circuit. Normally, this voltage will hold the grid of the tube at zero. The tube in the circuit conducts a relatively large current. The loadline shown in (D) shows this current to be nearly 2 ma. According to the loadline chart, the plate voltage due to this current is 25 volts.

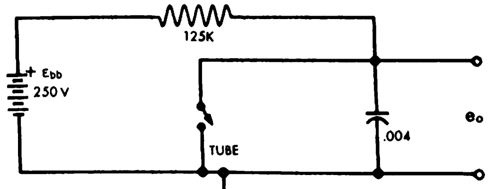
In radar equipment a time base is formed whenever a radar pulse is transmitted. Part of the transmitted energy is used to trigger the time base generator into action, thereby synchronizing the time base generator with the transmitter. This energy is shaped into a negative square wave that instantly drives the grid of the generator far below cutoff. As a result, the plate voltage tends to rise immediately to 250 volts, but since it cannot rise faster than the capacitor can charge, its rise is exponential. If a long time constant is used, the capacitor can only reach a small percentage of full charge before the grid cutoff voltage is removed. Remember that the first portion of a capacitor's charge (about 10 percent) is practically linear. This portion can be used to deflect the beam in a CRT and form a linear sweep, or linear time base. The capacitor and



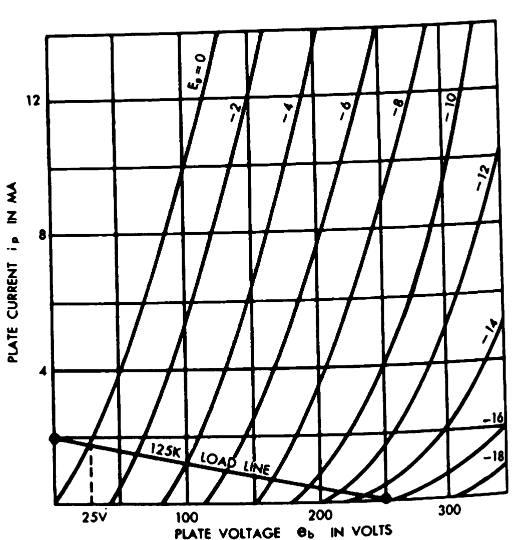
(A) CIRCUIT



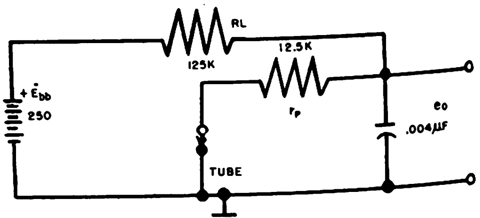
(B) WAVESHAPES



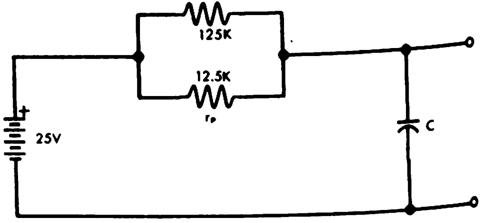
(C) EQUIVALENT DURING CHARGE



(D) LOAD LINE



(E) EQUIVALENT DURING DISCHARGE



(F) EQUIVALENT CIRCUIT DURING DISCHARGE USING THEVENIN'S THEOREM

Figure 4-35.—Hard-tube sweep generator.

plate-load resistor are therefore selected to have a long time constant so that the capacitor can charge to only a small amount of the applied voltage in the allotted time. This charge is the output of the sweep generator.

When the negative grid voltage is removed, the capacitor quickly discharges through the low resistance of the tube to its steady-state value of 25 volts. The long time inverval between transmitter pulses and the short time constant formed by the low tube resistance insure capacitor discharge to 25 volts before the next cutoff voltage occurs.

You can readily calculate the amplitude and linearity of a time base such as the one formed in the preceding discussion in the following manner. First, draw the loadline for the tube. The loadline shows that the voltage at the plate is 25 volts when the grid voltage is zero, and that cutoff for the tube is minus 16 volts when 250 volts is applied to the plate. Other factors to consider are that the minus 16-volt cutoff bias is easily exceeded by the minus 60 volts of the square pulse, which is 100 microseconds in duration (represented as time t in calculations), and that the applied voltage to the capacitor is 250 minus 25 or 225 volts. To find the capacitor voltage (e_c) after 100 microseconds, perform the following steps:

$$\text{time constant} = RC = 125 \times 10^{3} \times 4 \times 10^{-9}$$

$$\text{time constant} = 500 \times 10^{-6}$$

$$\text{time constant} = 500\,\mu\,\text{sec.}$$

Since t = 100 microseconds, the capacitor is ermitted to charge for 100/500 or 0.2 time onstant. By referring to the universal time onstant chart in figure 4-32, you will find that fter 0.2 time constant the capacitor will have eached a charge equal to 19 percent of the pplied voltage. The capacitor voltage (e_c) quals the applied voltage (225 volts) times 19 ercent plus the discharge voltage (25 volts) or

$$e_c = 225 \times 0.19 + 25 = 67.75 \text{ volts.}$$

The equivalent circuit during the charge is own in (C) of figure 4-35. Here the tube acts an open switch. If the rise continued at the itial rate, the curve would be perfectly linear. the initial rate, the voltage would rise 225 lts during the first time constant. Since it is owed to charge for 0.2 time constant, it would have risen 225 x 0.2 or 45 volts after this time. However, the actual rise is 42.75 volts (67.75 - 25). Thus, the actual curve varies from the linear curve by 2.25 volts (45 - 42.75).

When the grid voltage returns to zero, the equivalent circuit becomes as shown in (E) of figure 4-35 and also as the result of applying Thevenin's theorem as shown in (F). (This theorem states that any linear network containing one or more sources of voltage and having two terminals can be replaced by a simple generator having an internal impedance A and a generated voltage E, where E is the voltage that appears across the terminals when no load impedance is connected and A is the impedance across the terminals when all voltage sources are short-circuited.) The capacitor now discharges from 67.75 volts to 25 volts, through the internal resistance of the conducting tube, and the load resistor (R_L). At zero grid voltage, the plate voltage is 25 volts and plate resistance equals 12.5K. The resistance of the tube in parallel with the 125-K load resistor makes a total resistance of 11.35K. The time constant of this RC is 11.35 x 0.004 μf., or 45.5 microseconds. Because there are 300 microseconds between pulses, there is more than ample time for the capacitor to discharge to 25 volts.

The effect of varying elements in a hard-tube sweep generator is shown graphically in figure 4-36.

Typical Radar Sweep Generator

As shown in figure 4-37, the typical sweep-generator circuit in a radar set has a negative square wave applied to the grid of the tube. The duration of the square wave is adjusted to exactly the time required for the radar wave to travel 10, 50, or 100 miles and return. When the range switch is on the 10-mile position, the input voltage is the 10-mile square wave, and the 0.003-μf. capacitor is switched in the plate circuit. For the other ranges, larger capacitors are switched into the plate circuit and the input square wave is longer. The 1-megohm potentiometers in the plate circuits vary the amplitude of the output sawtooth wave. They are adjusted so that the sweep line on the CRT screen will extend to the required length.

Bootstrap Sweep Generator

A disadvantage of the sweep-generator circuit in figure 4-37 is its inability to develop a

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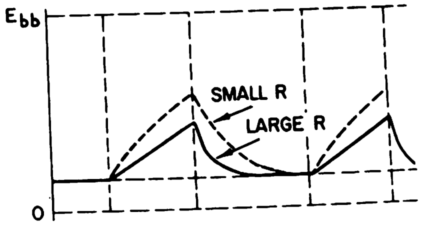
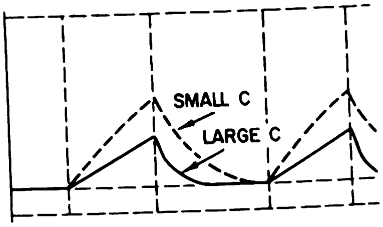
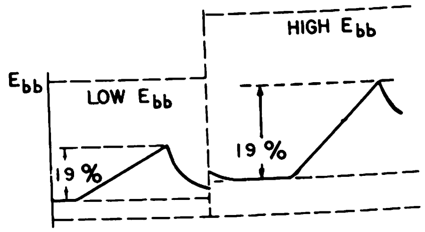
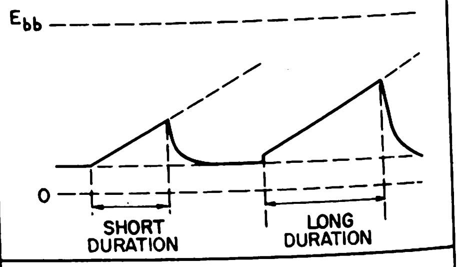
ELEMENT VARIED	EFFECT ON AMPLITUDE	EFFECT ON LINEARITY	EFFECT ON DURATION	WAVESHAPE
R IS INCREASED.	DECREASED. BECAUSE CONDENSER CHARGES SLOWER AND IS STOPPED BEFORE IT GETS AS HIGH.	IMPROVED. BECAUSE LOWER AMPLITUDE MEANS LESS OF CHARGING CURVE IS USED.	NO CHANGE. DURATION DETERMINED BY INPUT WAVESHAPE.	
C IS INCREASED.	DECREASED. CAPACITOR CHARGES SLOWER AND IS STOPPED BEFORE IT GETS AS HIGH.	IMPROVED. LOWER AMPLITUDE MEANS LESS OF CHARGING CURVE IS USED.	NO CHANGE DURATION DETERMINED BY INPUT WAVESHAPE.	
E_{bb} IS INCREASED.	INCREASED. CAPACITOR CHARGES TO SAME PERCENTAGE WHICH IS A HIGHER VOLTAGE.	NO CHANGE. CONDENSER CHARGES TO SAME PERCENTAGE AS BEFORE.	NO CHANGE.	
DURATION OF INPUT CUTOFF VOLTAGE INCREASED.	INCREASED. CAPACITOR CHARGES LONGER AND SO TO A HIGHER VOLTAGE.	DECREASED. MORE OF CHARGING CURVE IS USED.	INCREASED. BECAUSE INPUT DURATION IS INCREASED.	
AMPLITUDE OF INPUT SIGNAL INCREASED.	NO CHANGE IF SIGNAL WAS ALREADY CUTTING TUBE OFF.	NO CHANGE IF SIGNAL WAS ALREADY CUTTING TUBE OFF.	NO CHANGE	NO CHANGE IN PLATE WAVESHAPE.

Figure 4-36.—Effect of varying elements in hard-tube sweep generator.

linear sweep, because of the small amplitude of its output. This can be overcome by incorporating a bootstrap circuit.

The linear sweep-generator bootstrap circuit of figure 4-38 is essentially a circuit for generating a linear, sawtooth rise of voltage during the application of a negative rectangular pulse from the square-wave generator. To accomplish this, V_1 controls the charge and discharge of capacitor C_3. The cathode follower V2 and the

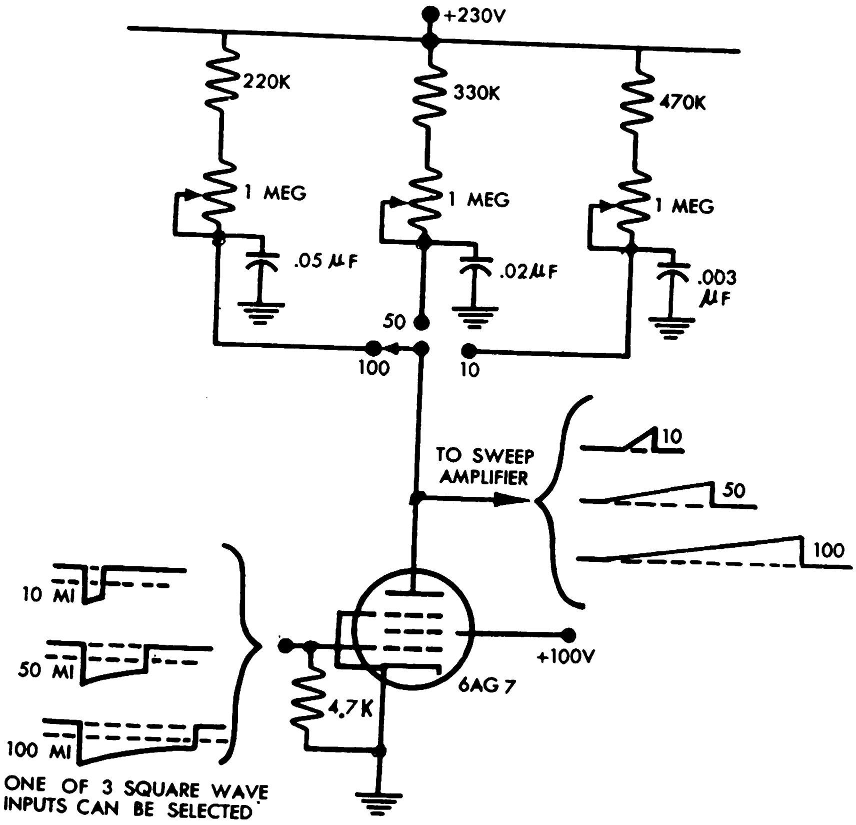


Figure 4-37.—Typical radar sweep generator.

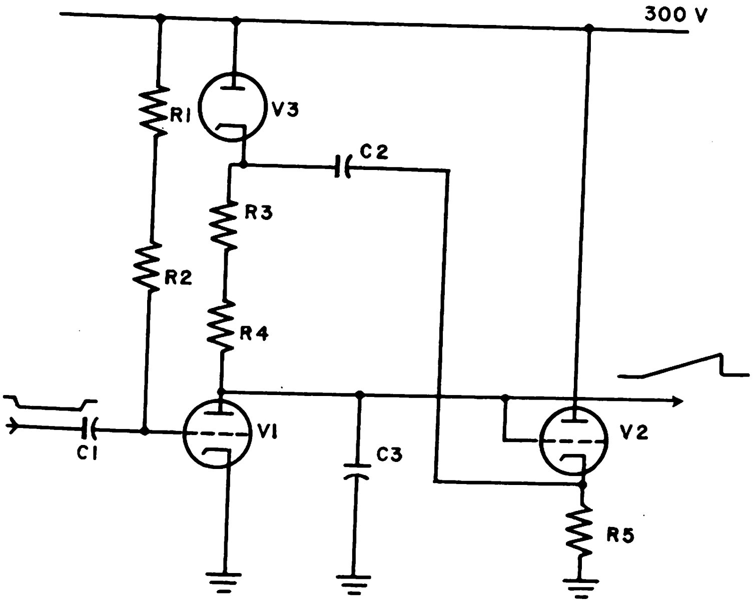


Figure 4-38.—A bootstrap sweep generator.

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bootstrap diode V_3 provide a means of making the charging curve of the capacitor linear. In the absence of a negative gate from the square-wave generator both triodes V_1 and V_2 and the diode V_3 are conducting. Under these circumstances, most of the B-plus voltage is across R_3 and R_4, and capacitor C_2 is charged almost to the B-plus voltage. Capacitor C_3 is charged only to the low plate potential of V_1. When the negative gate input reaches the grid of V_1, it cuts off that tube. The timing capacitor in the plate circuit of V_1 starts charging through R_3 and R_4. This rising voltage is in turn applied to the grid of the cathode follower V_2. The plate voltage of V_1 starts to rise toward the voltage of C_2, but because of R_5 the cathode follower this same plate-voltage rise is itself added to the voltage of C_2, so that the voltage drop across R_3 and R_4 remains constant as the plate voltage of V_1 rises.

Therefore, the current through R_3 and R_4 is constant, and voltage on the grid of V_2 (which is the output voltage) rises linearly. The bootstrap diode V_3 ceases to conduct when the potential of its cathode rises above that of its plate, and effectively disconnects the charging circuit from the B-plus supply. Thus, the voltage of the linear waveform is not limited to the B-plus voltage but continues to rise linearly until the negative gating pulse is removed from the grid of V_1. When V_1 begins conducting, C_3 discharges to its static low voltage level, and the extra voltage drop across R_5 disappears. Since the cathode of V_3 is then slightly less positive than its plate the tube conducts. The generator remains in this static state until another gating pulse arrives at V_1.

TRAPEZOIDAL WAVESHAPE GENERATOR

The sawtooth sweep generator previously described is suitable for any electrostatically deflected CRT. However, you will find that the majority of the larger radar sets employ magnetic deflection instead in cathode-ray tube circuits in which sweep voltages are applied to coils. In long range sweeps, the sawtooth voltage is adequate for a linear sweep, but on short ranges, a special sweep voltage with a trapezoidal waveform must be applied to overcome the effects of the L/R formed by the sweep coils.

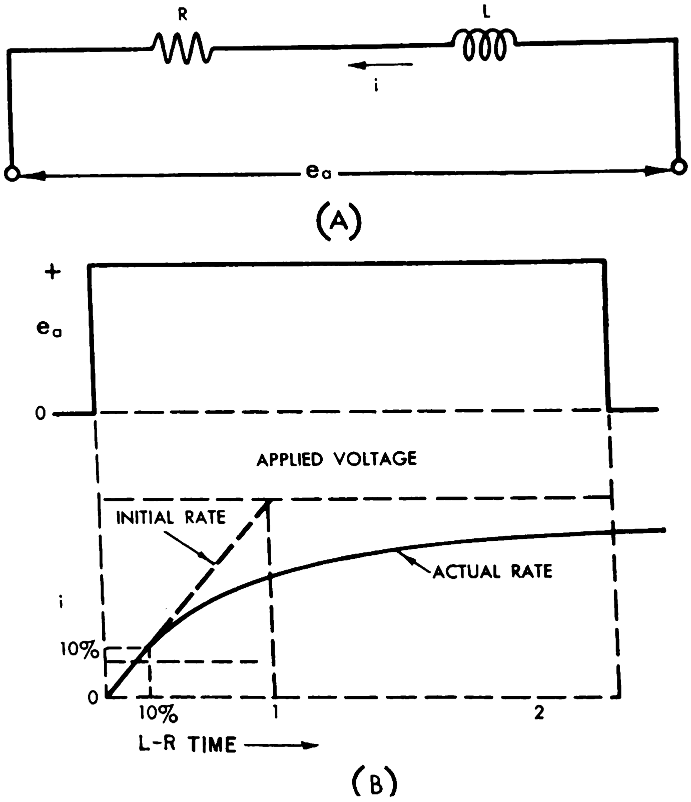

Figure 4-39.—Square wave applied to L/R circuit.

The deflection of the spot in a magnetic CRT ends upon a change in magnetic field strength. ce this magnetic field strength varies directly n the current in the deflection coils, any ear deflection of the spot requires a linear iation of the current through the deflection l. A fairly linear current change occurs enever a square wave is applied to an inductor he first 10 percent of the time constant is used. shown in figure 4-39, square wave e_a is lied to an L/R circuit. (Remember that all lection coil circuits are L/R combinations ause the coil wire and associated com- ents introduce resistance in series with the ual inductance of the coil.) In this L/R cuit the current change through the coil reases rapidly at first but the rate of in- ase becomes progressively slower as the tage drop across the resistor decreases the tage applied to the coil. During the first percent of the rise, the increase in current quite linear.

Making the L/R value much longer than the e of the applied voltage produces a reason- e linear sweep. Referring to the simple cuit in figure 4-40 (B) utilizing a square- ve input, you see a tube that is normally off by fixed bias. When the sweep is ready start, the grid voltage is brought up to zero h respect to the cathode by a positive square e. Plate current flows, increasing at a rate ermined by the inductance and resistance. s resistance is the plate resistance of the and the resistance of the coil. The time stant of the L/R circuit formed is long, therefore the current rise is slow. The pulse the grid ends before the current becomes high, thus keeping the current increase in first 10% or linear portion of the curve. n the tube is cut off the magnetic field pses, causing an oscillatory transient. The ients can be prevented either by a change e circuit or made harmless by blanking pot during this time.

is difficult to keep the series resistance l because the plate resistance of the um tube involved is never small. There- shorter time constants (larger R in ratio are accepted, and the applied voltage is ed to compensate for the large R. Re- g to (B) of figure 4-39, notice that if were no resistance in this circuit, the nt would increase indefinitely at the initial long the broken curve. This is because the fundamental relationship between the voltage and current in an inductor is

$$E = L\,di/dt$$

where E is the applied voltage, L the inductance, and di/dt is the instantaneous rate of change of current with respect to time. L and E are constant and time changes linearly; therefore the current i must change linearly to make the equation true. The rate decreases along the exponential curve because the voltage drop across the resistor, due to this same current through it, subtracts from the applied voltage to leave less voltage across the inductor. Less voltage causes the current to increase at a slower rate.

The effect of the resistor may be eliminated if the applied voltage is increased at the same rate that the resistor voltage increases. Under these conditions, the subtraction of the resistor voltage maintains a constant voltage across the inductor, and the current increases at a constant rate.

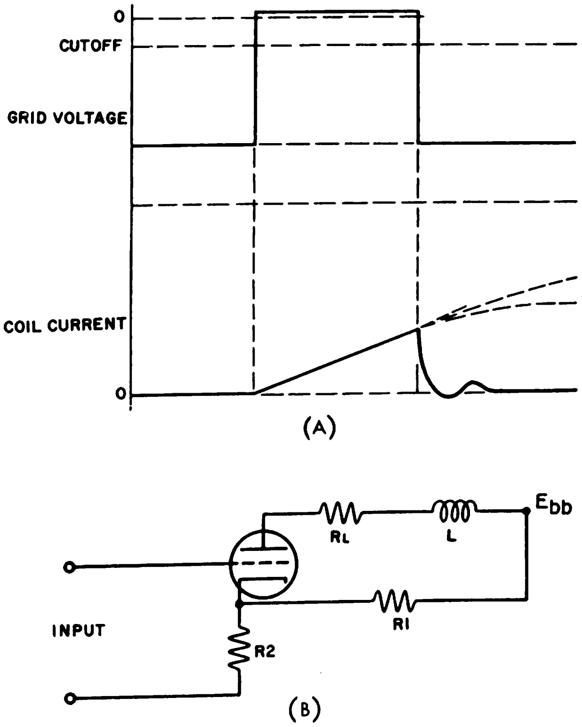

Figure 4-40.—Linear rise due to long time constant.

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Analysis of the Trapezoidal Waveshape

The applied waveshape just described is called a TRAPEZOIDAL WAVE. In the waveshape shown in figure 4-41, the initial instantaneous rise is called the JUMP voltage. It is this voltage which starts the current flow in the inductor. The slow increase is called the SLOPE voltage. Its action is to compensate continuously for the drop across the resistor.

A quantitative analysis shows that there is a direct relation between the L/R, the jump voltage, and the slope voltage. In addition, since the trapezoidal voltage is produced with an R/C circuit, there is a direct relationship between the L/R of the sweep amplifier and the RC of the sweep generator.

The jump voltage is the voltage which would be applied to a pure inductance. It is a constant value equal to L di/dt, where L is the inductance and di/dt is the rate of current change in amperes per second. As the current change also occurs in the resistor, you can use the Ohm's law formula E = IR to determine the voltage across the resistor. The facts are that R is constant and I is the same continuously changing current that is flowing through the inductor. Thus, according to Ohm's law the slope of the resistor voltage becomes R di/dt.

Important facts to remember are that in the determination of the waveshape required for any sweep coil, the ratio of the jump voltage to the slope voltage is the most essential quantity, and that the jump to slope ratio is equal to the time constant of the L/R circuit. The relationship expressed mathematically reads,

$$\frac{\text{jump}}{\text{slope}} = \frac{L\,di/dt}{R\,di/dt} = \frac{L}{R}$$

To learn to use this relationship, study the following sample problems:

PROBLEM 1.—Assume the CRT and coils in the CRT assembly have been assembled and that as part of a radar set, a linear time base for a 50-nautical-mile range is required—that is, the spot must swing across the scope at a constant rate in 620 microseconds (the approximate time of 50 radar miles of travel). Experiments with d-c current indicate that a current of 100 ma. causes the spot to move the required distance. Therefore, for a linear time base that covers the screen, the current in the coils must change at a constant rate from zero to 100 ma. in 620 microseconds. The required current waveshape is shown in (C) of figure 4-42. Further measurements indicate that the total resistance in the coil windings is 400 ohms and the inductance is 100 millihenries. The equivalent circuit of the coils is shown in (B). What jump voltage and what slope voltage are required to cause a perfectly linear sweep on the CRT?

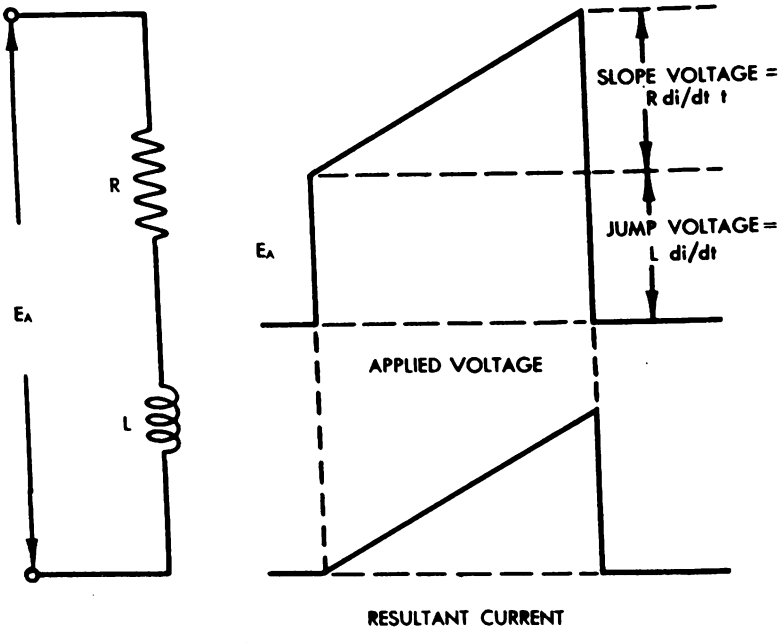

Figure 4-41.—Trapezoidal waveshape.

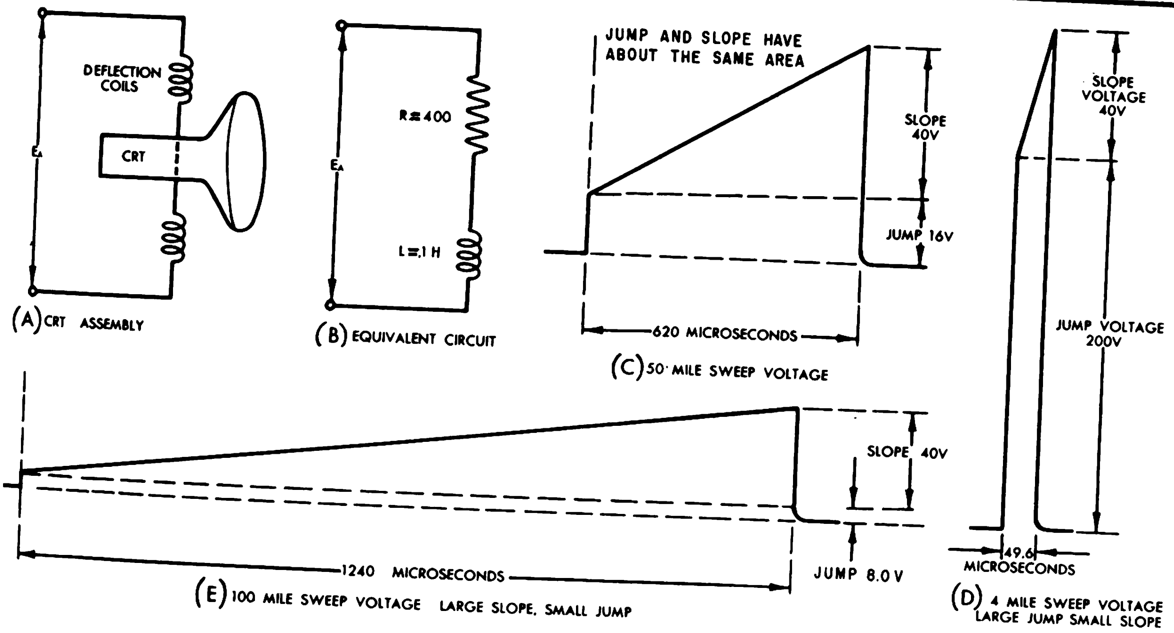

Figure 4-42.—CRT assembly and waveshapes for 4-, 50-, and 100-mile ranges.

Solution:

The voltage across the inductor E_L is L di/dt. Therefore, since L is 0.1 h, di is 100 ma., and dt is 620 microseconds, then

$$E_L = \frac{10^{-1} \times 10^{-1}}{620 \times 10^{-6}}$$

$$E_L = 16.1 \text{ volts.}$$

The resistor voltage slope is R di/dt

Therefore, it equals $\frac{400 \times 10^{-1}}{620 \times 10^{-6}}$, or 64,500 volts per second.

The change in voltage across the resistor is at a rate of 64,500 volts per second. Since the time base only lasts 620 microseconds, the voltage change will be 620 millionths of this value or 64,500 x 620 x 10^{-6}, or 40 volts. You can easily check this result as follows: The current at the end of the time base is 100 ma. and is the final resistor current. The resistance is 400 ohms; therefore, $E_R = IR = 0.1 \times 400$ or 40 volts. The required input waveshape, drawn to scale, is shown in (C) of figure 4-42.

PROBLEM 2.—Notice the difference in the waveshape when the same sweep coil is used for longer and shorter sweeps. In each case the final current is 100 ma. for full scale deflection; therefore, the final resistor voltage is always 40 volts (100 ma. through 400 ohms). Find the jump voltage for a 4-mile range.

Solution:

The sweep time is 12.4 microseconds per mile. Therefore, for four miles it is four times that or 49.6 microseconds. Substituting in the equation E_L = L di/dt,

$$E_L = \frac{10^{-1} \times 10^{-1}}{49.6 \times 10^{-6}}, \text{ or 200 volts.}$$

Since the 100 ma. is a smaller percentage of the final current when 200 volts is applied than when 16 volts is applied, the rise is more linear and the slope voltage is a smaller proportion of the total voltage. This condition approaches the applied square wave shown in figure 4-39. When the percentage of slope voltage becomes somewhat smaller, it may be safely omitted without serious nonlinearity in current rise.

PROBLEM 3.—Calculate the applied waveshape for the 100-mile range and find the jump voltage when the final slope voltage is still 40 volts across the 400-ohm resistor and the time is 1,240 microseconds.

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Solution:

Find the jump voltage, E_L, by the equation $E_L = L\ di/dt$

$$\text{Substituting, } E_L = \frac{10^{-1} \times 10^{-1}}{1,240 \times 10^{-6}} = 8.0 \text{ volt}$$

Since the current rise is very slow, only a a small voltage is applied to the inductor. In fact, the jump voltage is so small that it may be omitted altogether on this long range without appreciable change of the waveshape. The applied waveshape becomes a sawtooth waveshape similar to that used for the electrostatic CRT. The waveshapes for the 4-, 50-, and 100-mile ranges are drawn to scale in (C), (D), and (E) of figure 4-42. Notice that the small jump voltage goes with the long range and the large jump voltage goes with the very short ranges.

Trapezoidal Sweep Generator

Where it is necessary to supply a trapezoidal waveshape to a sweep coil, a vacuum tube and RC circuit may be used to produce the desired waveshape. Diagram (A) of figure 4-43 shows a simple vacuum tube circuit that will produce this kind of waveshape, and (B) shows the equivalent of the producing circuit. The triode serves only as a high-speed switch. When the tube is cut off by the driving pulse, the plate voltage rises toward the applied voltage at the rate the capacitor charges. However, some of the resistance of the RC circuit is between the plate and ground. The high initial charging current flows through this resistor and the capacitor, raising the voltage immediately toward the applied voltage. In the curves, the capacitor voltage and total resistor voltage curve are shown in (C). If R_2 is one-fourth the

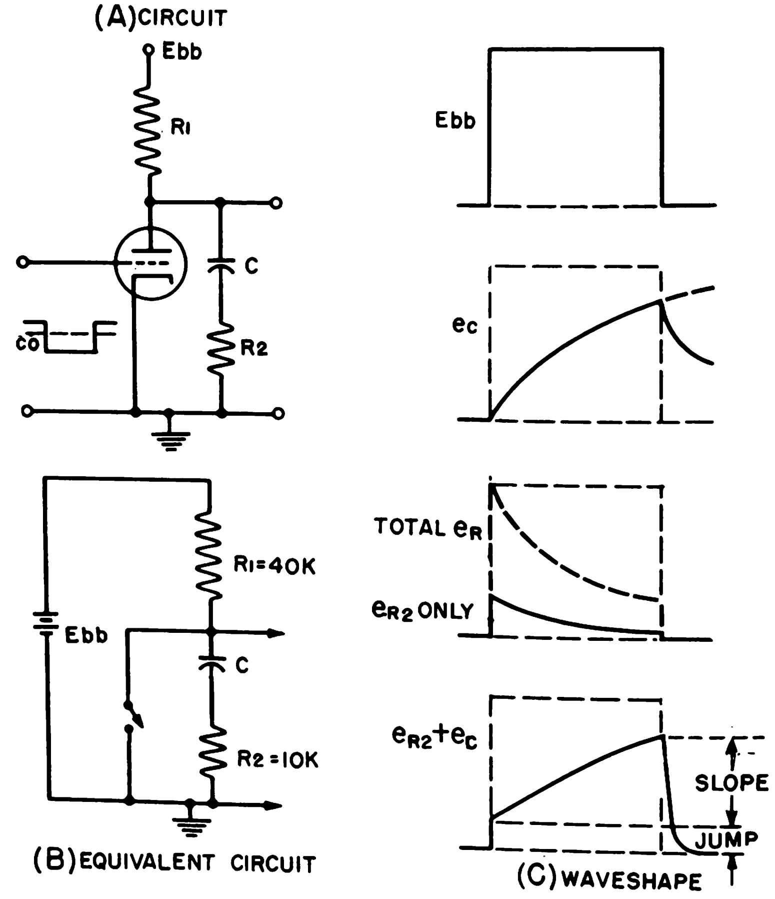

Figure 4-43.—Trapezoidal sweep generator.

size of R_1, one-fourth of the voltage will be across it at all times. The curve for the R_2 voltage is a miniature replica of the total resistor voltage. The output voltage is the sum of the R_2 voltage and the capacitor voltage. This total voltage is the trapezoidal voltage required for the sweep coil circuit.

As before, the two elements—jump and slope—form the waveshape in the sweep coil. The ratio of the jump to slope is L/R. To produce the same jump-to-slope ratio with an RC circuit, it is necessary that the RC circuit be designed so that R_2C is equal to the L/R of the sweep coil circuit. Mathematically, the relationship is expressed as $L/R = R_2C$.

This equation is derived as follows:

First, consider the jump voltage when the voltage E_{bb} is applied to the circuit. The total voltage E_{bb} appears across the resistors R_1 and R_2. The proportion of the voltage that appears across R_2 is expressed by the following equation:

$$E_{R2} = \frac{E_{bb}R_2}{R_1+R_2}$$

If R_2 is much smaller than R_1, you can simplify the equation and get an approximate answer by dropping R_2 from the denominator. The equation now reads,

$$E_{R2} = \frac{E_{bb}R_2}{R_1}$$

Second, consider the slope, being sure not to confuse slope with the final slope voltage. Slope is a rate of so many volts per second while final slope is so many volts at the end of the rise. The initial charging rate of the capacitor is such that it would charge the capacitor to the applied voltage in one time constant. If only a small part at the start of the curve is used, then the initial rate is the slope. Since the voltage increases at a rate of one E_{bb} per time constant,

$$\text{Slope} = \frac{E_{bb}}{(R_1 + R_2)\,C}$$

When R_2 is quite small, you may disregard it for simplicity. Therefore, the slope equation reads,

$$\text{Slope} = \frac{E_{bb}}{R_1C}$$

Using the simplified equation, you can express the relation of the jump to slope as follows:

$$\frac{\text{jump}}{\text{slope}} = \frac{\dfrac{E_{bb}R_2}{R_1}}{\dfrac{E_{bb}}{R_1C}}$$

$$= \frac{E_{bb}R_2}{R_1} \times \frac{R_1C}{E_{bb}}$$

$$\frac{\text{jump}}{\text{slope}} = R_2C$$

You know this is an approximation, but you can see that the jump-to-slope ratio is nearly equal to the product of R_2 times C. For linear current increase, therefore, the time constant of the deflection coil circuit (L/R) should equal R_2C.

Design Considerations in a Trapezoidal Generator

In the practical utilization of the principles just described, it is usually necessary to make the sweep coil a part of the plate circuit of a power amplifier tube in order to obtain the high currents with the desired waveshape. The trapezoidal waveshape is then generated at a low level and amplified by the power amplifier tube.

To see how the details are worked out, study the example of a complete generator and sweep coil circuit in figure 4-44. The quantitative values worked out are for the coil used for producing the 50-mile sweep voltage described earlier. In the design of this circuit, you will find it convenient to start with the sweep coil and work backwards to the sweep generator. Therefore, the waveshapes which are shown and the analysis which follows are in reverse order.

The 50-mile sweep voltage coil has an inductance of 100 millihenries and a resistance of 400 ohms. A linear time base requires a linear current rise of 100 ma. in 620 microseconds, which can be accomplished with a jump voltage of 16 volts (from previous calculations). Since

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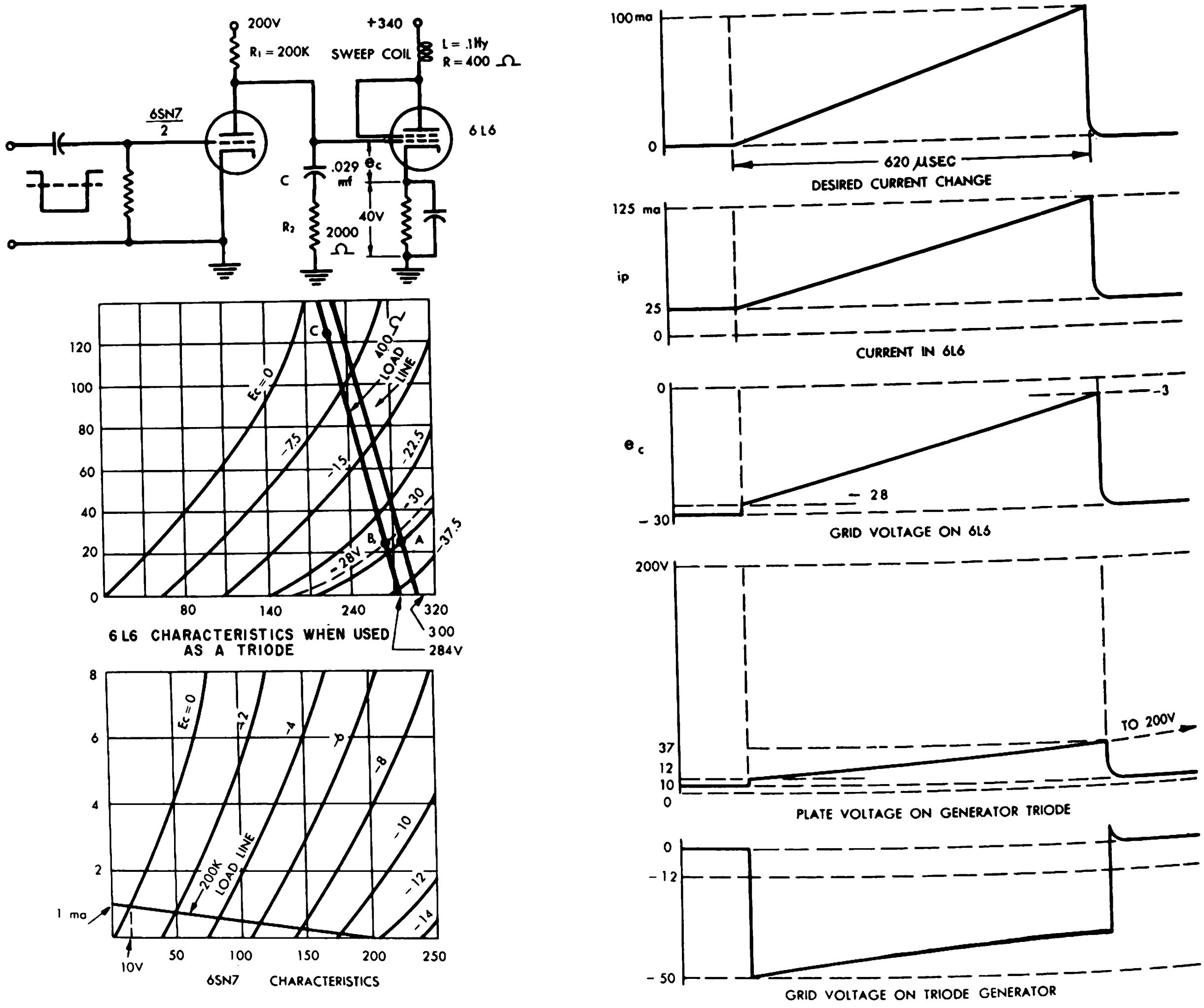

Figure 4-44.—Complete generator and sweep coil circuit.

this applied voltage is from the plate circuit and is due to grid-voltage change, which is amplified in the tube, the required jump in grid voltage is only a fraction of the plate-voltage change.

In the circuit illustrated, the sweep coil is in the plate circuit of a 6L6 power amplifier. The 100 ma. current change actually starts from 25 ma. instead of zero to take advantage of the more linear part of the tube characteristics. The loadline is drawn from the 400-ohm resistance of the coil. The voltage on the grid of the 6L6 between sweep voltages, first tube conducting, is plus 10 volts, but 40 volts bias makes the grid-to-cathode voltage minus 30 volts. Therefore, the waveshape starts forming at point A on the loadline. Then the sudden grid voltage change on the triode causes a change of 16 volts in the plate circuit of the 6L6. The current increase in the coil generates 16 volts of back e.m.f., reducing the effective plate voltage by 16 volts. Thus a new loadline is drawn from 300 minus 16 or 284 volts. The grid voltage must change to point B on the loadline for a 16-volt change in the plate. The current has just started increasing above 25 ma., so point B is at 25 ma. plate current and 284 volts plate voltage. The grid-voltage change is from minus 30 to minus 28 volts as read from these characteristic curves. Therefore, the jump required at the grid of the 6L6 is 2 volts.

After the jump, the slope occurs. The current must rise at a constant rate to 125 ma. At 125 ma. the grid voltage, as read from the characteristic curves, is minus 3 volts.

Note the difference in waveshape between the earlier circuit in (C) of figure 4-42 and the grid-voltage curve for the 6L6 in figure 4-44. The slope component is many times as large as the jump component at the grid while the slope and jump are almost the same in the circuit in figure 4-42. The difference is due to the plate resistance of the 6L6 tube being in series with the coil. The additional resistance requires a much larger slope component.

The voltage change across the resistor R_2 and capacitor C in the circuit must be the same as the required grid voltage change. The sweep-generator components must be selected for this waveshape.

First consider the plate voltage required on the 6SN7. The slope must be linear, which means the charge must be limited to the first 10 percent of the charging curve. The voltage slope component has a final amplitude of 25 volts. The slope starts from 10 volts. If 100 volts are used as the applied voltage, 25 volts, being 25 percent of 100 volts, would be too nonlinear. Using 200 volts, and subtracting the 10 volts of original charge (plate voltage when the 6SN7 is conducting), 25 volts are 25/190 or 13.3 percent of full charge. This will be acceptable in this case because a higher voltage will raise the plate voltage, with the 6SN7 conducting, to more than 10 volts, which would require increasing of the 6L6 bias.

With 200 volts plate voltage, a load resistor must be selected which will hold the plate voltage at 10 volts while the 6SN7 is conducting and grid voltage is zero. As shown by the loadline on the 6SN7 characteristic curves, a 200-K resistor will accomplish this.

Next determine the capacitor size from the following data:

$$C_c = 25 \text{ volts}$$

$$E_{bb} = 200 - 10 = 190 \text{ volts}$$

$$t = 620 \text{ microseconds}$$

$$R = 200K$$

The percent of full charge $= \dfrac{C_c}{E_{bb}} = \dfrac{25}{190} = 13.3$ ercent

From the universal time constant chart in figure 3-10, 13.3 percent of charge equals 0.107 time constant. This means that 620 microseconds is 0.107th of a time constant or 0.107 RC.

Since $620 \times 10^{-6} = 0.107\ RC$
Then,

$$C = \frac{620 \times 10^{-6}}{0.107\ R} = \frac{620 \times 10^{-6}}{1.07 \times 10^{-1} \times 2 \times 10^{5}}, \text{ or}$$

$$C = 290 \times 10^{-10} = 0.029\ \mu f.$$

The last item, the size of R_2, provides the jump voltage, which is 2 volts. You can calculate R_2 by transposing in the equation

$$\text{jump} = \frac{E_{bb} R_2}{R_1}$$

This gives,

$$R_2 = \frac{\text{jump} \times R_1}{E_{bb}}$$

Substituting,

$$R_2 = \frac{2 \times 2 \times 10^{5}}{2 \times 10^{2}} = 2{,}000 \text{ ohms}$$

The pulse required to cut off the 6SN7 according to the characteristic curves must be more than 12 volts negative. The negative square wave, having an amplitude of 50 volts, is more than ample for this purpose.

In the cathode-ray tube deflection coil circuit, a separate coil may be provided which will cancel the magnetic field caused by the residual 25 ma. current in the 6L6 tube. This causes the magnetic field strength to be zero between sweeps even though 25 ma. is flowing in the sweep coil.

In the chart in figure 4-45 which summarizes the effect of varying the sizes of the component parts of the trapezoidal sweep generator, notice that varying R_1, the plate-load resistor, affects the overall amplitude of the waveshape but has little effect on the jump-to-slope ratio. Varying the capacitor size changes the slope only, while varying R_2 changes the jump voltage only.

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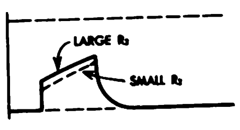
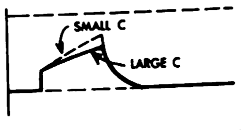
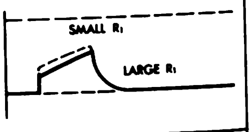
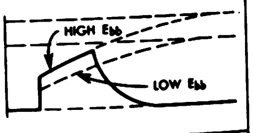
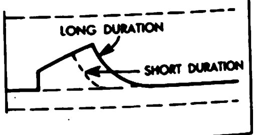
CIRCUIT CHANGE	EFFECT ON JUMP VOLTAGE	EFFECT ON SLOPE AMPLITUDE	EFFECT ON SLOPE LINEARITY	EFFECT ON DURATION	WAVESHAPE
INCREASE R_2	INCREASED BECAUSE RATIO R_2/R_1 IS INCREASED	NO CHANGE RC IS STILL APPROXIMATELY THE SAME	NO CHANGE RC IS UNCHANGED	NO CHANGE DURATION IS DETERMINED BY GRID PULSE	 LARGE R_2 SMALL R_2
INCREASE C	NO CHANGE RATIO R_2 R_1 IS UNCHANGED	SLOPE IS LESS FINAL AMPLITUDE LESS BECAUSE RC IS LONGER, CHANGE IS SMALLER PERCENTAGE	IMPROVED BECAUSE SMALLER PART OF CHARGE CURVE IS USED	NO CHANGE	 SMALL C LARGE C
INCREASE R_1	SMALLER RATIO R_2 R_1 IS LESS	GREATER BECAUSE RC IS SHORTER, C CHARGES TO HIGHER VOLTAGE	DECREASED BECAUSE GREATER PART OF CHARGING CURVE USED	NO CHANGE	 SMALL R_1 LARGE R_1
INCREASE E_{bb} (PLATE SUPPLY VOLTAGE)	INCREASED DUE TO GREATER APPLIED VOLTAGE	INCREASED DUE TO HIGHER VOLTAGE CHARGE LIMIT	NO CHANGE SAME RC SAME DURATION SAME PERCENTAGE	NO CHANGE	 HIGH E_{bb} LOW E_{bb}
DURATION OF DRIVING PULSE INCREASED	NO CHANGE SAME APPLIED VOLTAGE, SAME R_2 R_1 RATIO	NO CHANGE SAME APPLIED VOLTAGE, SAME RC_1	DECREASED BECAUSE GREATER PART OF CHARGE CURVE USED	INCREASED BECAUSE INPUT PULSE IS LONGER	 LONG DURATION SHORT DURATION

Figure 4-45.—Effect of varying elements in a trapezoidal sweep generator.

QUIZ

1. In a thyratron sawtooth generator, increasing the bias voltage will
   a. increase sawtooth linearity
   b. increase frequency
   c. decrease amplitude of sawtooth
   d. decrease frequency

2. The action in the grid circuit of a grid clamper is the same as
   a. positive-diode clamper
   b. negative-diode clamper
   c. positive grid limiter
   d. negative grid limiter

3. In figure 4-38, increasing the size of C_3 will
   a. increase amplitude of sawtooth
   b. decrease flyback time
   c. increase linearity of sawtooth
   d. decrease linearity of sawtooth

4. In a grid limiter the operation of the grid circuit is the same as a
   a. positive limiter
   b. negative limiter
   c. positive clamper
   d. negative clamper

5. In radar indicators, clamping circuits are used to establish the d-c reference at the CRT because
   a. greater gain can be realized from use of many clamping circuits in series
   b. the clamping circuits synchronize the sweeps both horizontally and vertically
   c. the coupling capacitors between amplifier stages pass only the a-c components of a signal and reject the d-c reference level
   d. d-c coupling between amplifier stages cannot establish a d-c reference level

6. In figure 4-17, the 8-μf. capacitor (in cathode of second triode) shorts. The plate waveform of V_2 would be
   a. a square wave
   b. negative spikes with switch in either position
   c. a low d-c voltage
   d. positive spikes with switch in either position

7. If a sine wave is applied to a positive series-diode limiter, limiting at zero potential, the output during the positive portion of the input will be
   a. a positive voltage
   b. a negative voltage
   c. zero volts
   d. both positive and negative voltage

8. In a hard-tube sawtooth generator, increasing B+ will
   a. improve linearity of sawtooth
   b. increase amplitude of sawtooth
   c. increase frequency
   d. decrease amplitude of sawtooth

9. The plate resistance of a typical conducting diode is approximately
   a. 5 ohms
   b. 500 ohms
   c. 5,000 ohms
   d. 50,000 ohms

In a radar set employing electromagnetic deflection, to switch from a long range to a short range, you should
   a. increase slope voltage only
   b. decrease slope voltage only
   c. increase both jump and slope voltage
   d. increase jump voltage only

Clamping circuits are used in sweep circuits to
   a. limit the polarity of the sweep
   b. make the sweep linear
   c. limit the amplitude of the sweep
   d. start each sweep at the same potential

Saturation limiting with a small grid signal occurs in a tube in which the plate circuit contains a
   a. low plate-load resistor and a high plate-supply voltage
   b. high plate-load resistor and a high plate-supply voltage
   c. low plate-load resistor and a low plate-supply voltage
   d. high plate-load resistor and a low plate-supply voltage

13. In a negative series-diode limiter, the diode conducts
   a. when the input is positive
   b. when the input is negative
   c. at all times
   d. when the output is negative

14. To obtain a trapezoidal waveform from a hard-tube sawtooth generator,
   a. a resistor is placed between sweep capacitor and ground
   b. a resistor is placed in parallel with sweep capacitor
   c. the sweep capacitor is replaced with a resistor
   d. two sweep capacitors are connected in series

15. The function of a limiter, or clipper, is to restrict a signal in
   a. amplitude without affecting the shape
   b. amplitude without affecting the frequency
   c. frequency without affecting the shape
   d. frequency without affecting the amplitude

16. In figure 4-17, the 0.002-μf. coupling capacitor is increased to 0.2 μf. capacity. The waveform at plate of V_2 would be
   a. all positive spikes
   b. all negative spikes
   c. both positive and negative spikes
   d. high amplitude square wave

17. Which of the following statements about grid-limiting is true?
   a. Either positive or negative peaks may be clipped.
   b. Limiting occurs when electrons flow from the cathode to the plate.
   c. The amount of clipping depends on the ratio of grid-cathode resistance to series-grid resistance.
   d. A large resistor is required in series with the plate.

18. A positive-diode clamper will
   a. clamp peak of input to clamping potential
   b. clamp base of input to clamping potential
   c. limit positive portion of input
   d. limit negative portion of input

19. The parallel-diode limiter differs from the series-diode limiter in
   a. having an output only when conducting
   b. having an output only when nonconducting
   c. being essentially a voltage-divider circuit
   d. limiting when biased below cutoff

20. A negative-diode clamper will
   a. clamp peak of input to clamping potential
   b. clamp base of input to clamping potential
   c. limit the positive portion of input
   d. limit the negative portion of input

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21. A high amplitude sine wave is applied to a parallel-diode shunt limiter. Each limiter is limiting at a low bias voltage. The output will be a
    a. sine wave
    b. sine wave with positive portion clipped
    c. sine wave with negative portion clipped
    d. low amplitude square wave

22. A thyratron oscillator can be stabilized in frequency by a synchronizing sinusoidal waveform only when the frequency of the synchronizing signal is
    a. exactly the same as the fundamental of the oscillator
    b. slightly below the fundamental of the oscillator
    c. slightly below the fundamental, harmonic, or subharmonic of the oscillator
    d. slightly above the fundamental, harmonic, or subharmonic of the oscillator

23. An overdriven amplifier achieves both saturation and cutoff limiting by the use of a
    a. high plate-supply voltage, a high plate-load resistor, and a series-grid resistor
    b. low plate-supply voltage, a high plate-load resistor, and a large signal input
    c. high plate-supply voltage, a low plate-load resistor, and a small signal input
    d. low plate-supply voltage, a high plate-load resistor, and a series-grid resistor

24. In a negative shunt diode limiter, limiting at a negative potential, the output will be the same as the
    a. input
    b. positive portion of the input
    c. negative portion of the input
    d. input with the negative portion clipped at the limiting potential

CHAPTER 5

SPECIAL CIRCUITS—CONTINUED

SQUARE-WAVE GENERATOR

Some of the information dealing with multi- ibrators, as presented in this chapter, may eem repetitious of *Basic Electronics*, NavPers 0087. Since this chapter is written for Aviation lectronics Technicians First and Chief, the eatment of multivibrators must be more orough. The preliminary data is given as an d in introducing the more complicated aspects the subject.

The multivibrator (square-wave generator) a form of relaxation oscillator. There are veral different types in use, depending on the nction they are required to perform. They are ed for time sharing, gating, counting, and ning bases. These circuits either produce a ecified waveshape repeatedly as long as power supplied or produce one wave when pulsed, d remain inactive until another pulse is ap- ed to the circuit; then they produce another ve. The output waveshape is the same re- dless of the waveshape or amplitude of the iating or TRIGGER pulse. Those which run tinuously with only power applied are called e-running multivibrators. Those which pro- e one complete cycle of operation for each chronizing pulse are called ONE-SHOT, ONE- CLE, or MONOSTABLE. Those which produce a half cycle of operation for each synchro- ng pulse are called BISTABLE, FLOPOVER SCALE-OF-TWO circuits. The frequency of -running multivibrators, as with other types scillators, is influenced by all voltages and ponent sizes associated with the circuits. refore, although such circuits have only fair uency stability when free running, adequate ility is readily achieved from a reliable a-c hronizing voltage.

he square waveshape produced can be dif- ntiated to produce accurately spaced peaked shapes. The duration and amplitude of any of aveshapes are readily varied. Time delayed s can be produced by triggering a multivibrator with a peaked wave, letting it go through a cycle, and obtaining a new peaked wave somewhat later from the square wave produced.

The Plate-Coupled Multivibrator

The plate-coupled multivibrator is the simplest of the multivibrators. It produces a wave which is almost square when properly designed, and gives an almost perfect square wave when additions are made to the basic circuit. Note in figure 5-1 that basically this multivibrator consists of two triode amplifier stages, where the output of the second stage is introduced back into the input of the first. The phase inversion through the circuit is 360 degrees and any slight change in the first tube will be amplified through the circuit and will cause a greater change in the same direction in the first tube. That is, feedback is IN PHASE and the circuit will oscillate. There are no elements in the circuit to limit the feedback to any one frequency, so feedback occurs at all frequencies. Hence, a square wave containing several hundred frequencies is produced.

Looking at the action from the point of view of transients—that is, following each voltage change step by step—there are four different conditions that exist during one cycle of operation. They are as follows:

1. An extremely rapid change from V_1 conducting to V_2 conducting.
2. A long period during which V_1 is cut off and the circuit is relaxed.
3. A second violent change as V_1 conducts driving V_2 beyond cutoff.
4. A long period during which V_2 is cut off and the circuit is relaxed.

The cycle repeats as condition one follows condition four. The rapid changes just described are indicated by the vertical parts of the waveshapes in figure 5-1. These changes ordinarily occur in a few microseconds, and are so fast

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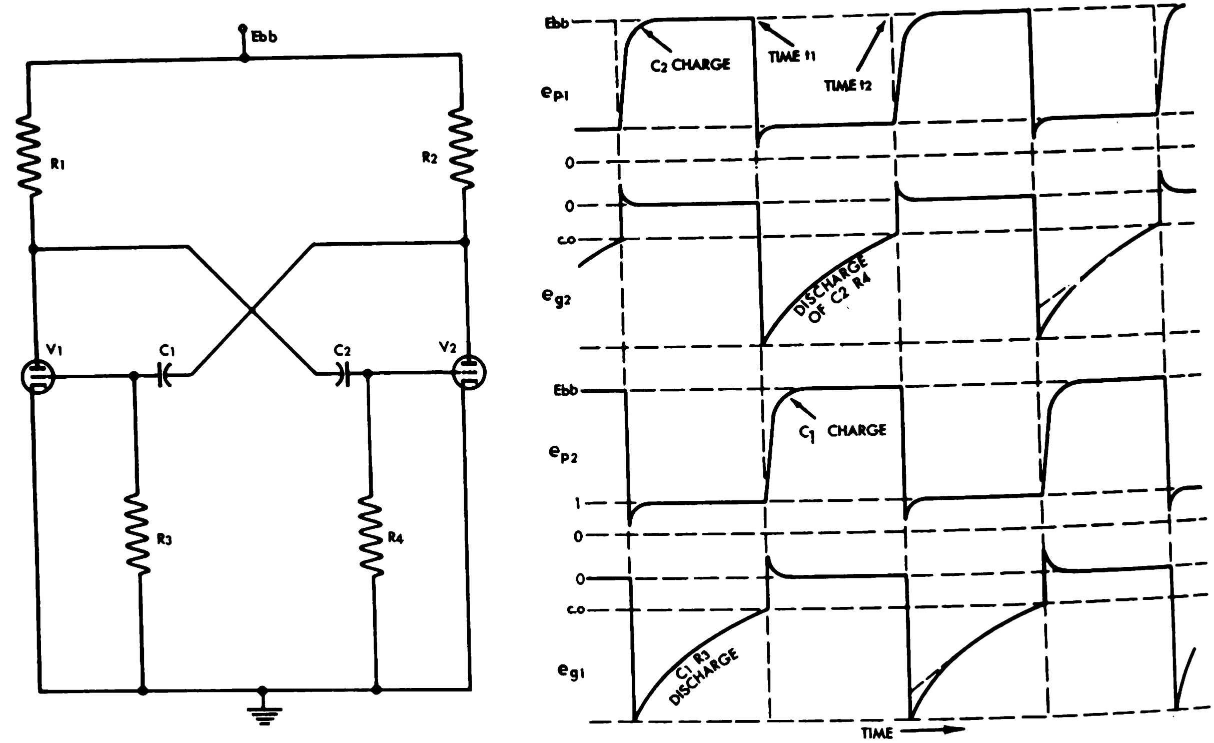


BASIC MULTIVIBRATOR CIRCUIT

WAVESHAPES

Figure 5-1.—Plate-coupled multivibrator.

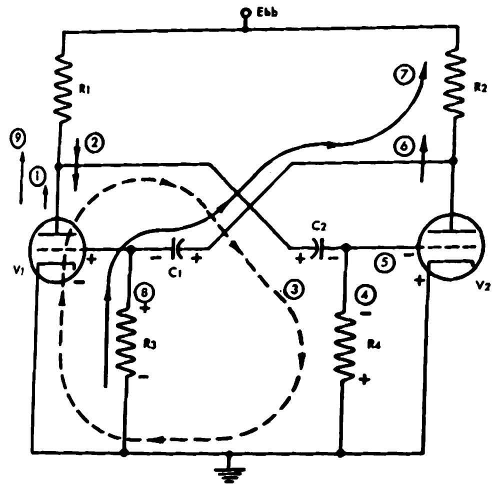
that the spot on a CRT becomes invisible when the waveshape is observed on an ordinary oscilloscope. The long relaxation periods are represented by the nearly constant voltages between switchover times.

CIRCUIT OPERATION

Refer to figure 5-2. When the filament voltages are on and the plate voltage is applied, current flows in both tubes. If the circuit components are the same in both tube circuits and both tubes are of the same type, the circuit is said to be SYMMETRICAL, and both currents should be equal. But it is impossible to obtain a perfect balance in the circuit, due to the nonuniformity of available parts and the irregular way in which emission occurs from the cathode. Any slight change in current in one tube that is not accompanied simultaneously by a similar change in the other tube will start oscillation.

Assuming that a slight current increase has occurred in the tube V_1, the following series of events then occur in rapid order: The increase of current in V_1 increases the voltage drop across R_1 which lowers the plate-to-ground voltage at V_1. This lower voltage is now less than the charge on C_2, and the capacitor C_2 discharges toward the new plate voltage. The discharge current flows through R_4 making the grid end negative. The negative grid of V_2 decreases the current in V_2. This reduces the drop across R_2, causing the plate-to-ground voltage at V_2 to be higher. Capacitor C_1 is between this plate and ground and therefore must charge to the new higher voltage. The charging current flows through R_3 toward the plate-supply voltage as shown by solid arrows in figure 5-2. This current causes the top of R_3 to be positive, and therefore the grid of V_1 to be positive. The positive grid causes the original slight increase of current to become a tremendous current increase. As the changes go around the circuit, a great voltage drop occurs at the plate of V_1 and grid V_2 is made more negative, current in V_2 is decreased more, plate voltage at V_2 goes up, making the grid of V_1 more positive and further increasing the V_1 plate current.

This is a cumulative process which continues until the current in V_2 is decreased to zero by a



① CURRENT INCREASES IN V_1

② VOLTAGE DROPS AT PLATE OF V_1 DUE TO INCREASED VOLTAGE ACROSS R_1.

③ CAPACITOR C_2, NOW CHARGED HIGHER THAN APPLIED VOLTAGE, DISCHARGES TOWARD NEW LOWER VOLTAGE; DOTTED LINES SHOW CLOSED DISCHARGE CIRCUIT.

④ DISCHARGE CURRENT MAKES TOP OF R_4 NEGATIVE WITH RESPECT TO BOTTOM.

⑤ SINCE GRID AND CATHODE ARE CONNECTED TO R_4, GRID BECOMES NEGATIVE WITH RESPECT TO CATHODE.

⑥ MORE NEGATIVE GRID AT V_2 DECREASES CURRENT RAISING VOLTAGE AT PLATE OF V_2.

⑦ A CURRENT FLOWS THROUGH PATH OF ARROWS TO CHARGE CONDENSER C_1 TO NEW HIGHER VOLTAGE.

⑧ THE CHARGING CURRENT MAKES THE TOP OF R_3 POSITIVE WITH RESPECT TO BOTTOM AND CONSEQUENTLY, THE GRID OF V_1 IS POSITIVE.

⑨ THIS CAUSES A GREAT INCREASE IN CURRENT IN V_1, WHERE THE ORIGINAL SMALL INCREASES OCCURRED

Figure 5-2.—Sequence of changes in multivibrator.

ld voltage far below cutoff. This action does not cur in steps as the explanation may seem to ply, but is a smooth and very rapid transition.

With zero current through V_2 the plate voltage comes equal to the supply voltage since there o voltage drop across R_2. C_1 quickly charges this value by grid current flow in V_1. After t, current through R_3 is zero; hence the grid-cathode voltage is zero. The plate voltage of remains at a constant low value while the grid tage is zero; so the capacitor C_2 continues to charge toward that value. While discharging, current (dotted lines) holds V_2 cut off. Every-g is at a standstill in the circuit except for slow discharge of C_2. Of the four conditions ed at the start of this discussion on the plate-pled multivibrator this corresponds to con-on four. The slow discharge of C_2 continues the voltage across C_2 becomes lower and r. The voltage across R_4 continuously equals C_2 voltage in accordance with Kirchhoff's ge law, so the R_1 voltage decreases. Upon hing a voltage just less than the cutoff volt-for V_2, a slight current starts flowing through V_2. This ends the period of inactivity in the circuit as swift changes follow this slight current.

The current lowers the V_2 plate voltage. C_1 starts to discharge, making the grid of V_1 negative. The resultant decrease in plate current raises the V_1 plate voltage. C_2 now recharges to the new V_1 plate voltage. The C_2 charging current makes the grid of V_2 positive and the original current is increased tremendously. This regenerative process continues until V_1 is cut off by the discharge of C_1. At this point, V_1 plate voltage rises quickly to the plate-supply voltage, C_2 charges swiftly to supply voltage through V_2 grid current, and the plate voltage of V_2 steadies at a low value. This ends the rapid changes during condition one.

The second inactive period occurs as V_1 is held nonconducting by the slow discharge of C_1. The discharge continues until the C_1 voltage is just below cutoff for V_1. This period is as described for condition two.

Then the slight current in V_1 repeats the first rapid change described above. In the waveshapes in the basic circuit diagram in figure 5-1, the long period between time t_1 and t_2 is the time that V_2 is cut off, and the exponential grid-voltage decrease of e_{g2} shows how long the capacitor C_2 can hold V_2 nonconducting. At time t_2 the rapid change just described occurs, while the half cycle following that is the time V_1 is cut off.

In summary, the operation of this circuit consists of long periods of time when one tube conducts a high current while the other tube is cut off, followed by an extremely rapid change to the other tube conducting and the first tube cut off.

The slow discharge of the capacitors is due to the long time constant of the discharge circuit. In the waveshape in the basic circuit diagram in figure 5-1, the grid voltage is shown as going positive for short periods of time. This occurs when the other plate is rising toward supply voltage. The capacitor is recharging, making the top of the grid resistor positive. The resultant positive voltage on the grid makes the grid act as a diode plate, and part of the emitted electrons flow to the grid and into the capacitor. This ready source of electrons charges the capacitor quickly. That is, the grid-to-cathode equivalent resistance is very small, forming a short RC during the capacitor charge. The positive-going grid causes an extra dip in plate voltage, which makes the grid of the other tube more negative than normal. The effect, if the grid did not become positive, is shown by dotted lines in the waveshapes in the basic circuit diagram.

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QUANTITATIVE ANALYSIS

It is fairly easy to calculate the frequency and approximate voltage throughout a given circuit of this type. Consider, for example, the circuit shown in figure 5-3 (A). A plate voltage of 300 volts is applied to a 6SN7 dual triode with the circuit components shown. The plate voltage of V_1 varies between the value corresponding to zero grid voltage and the value corresponding to zero plate current. You can determine these values from a 20-K loadline on the 6SN7 characteristic curves. The loadline crosses the zero grid-voltage line at a plate voltage of 97 volts. At zero plate current, the plate voltage is 300 volts. From this information you can construct the plate-voltage waveshape.

All this plate-voltage change occurs across the grid resistor on V_2 at the first instant. The resistor voltage is the grid voltage for V_2; so the grid will swing negative by the same amount that the plate voltage drops. The plate voltage drops from 300 to 97, or 203 volts. The grid is at zero when the plate-voltage drop occurs, so the grid immediately goes 203 volts negative. Then the capacitor starts discharging down to 97 volts. The discharge will be exponential. The equivalent circuit during the discharge is shown in (D) of figure 5-3. The

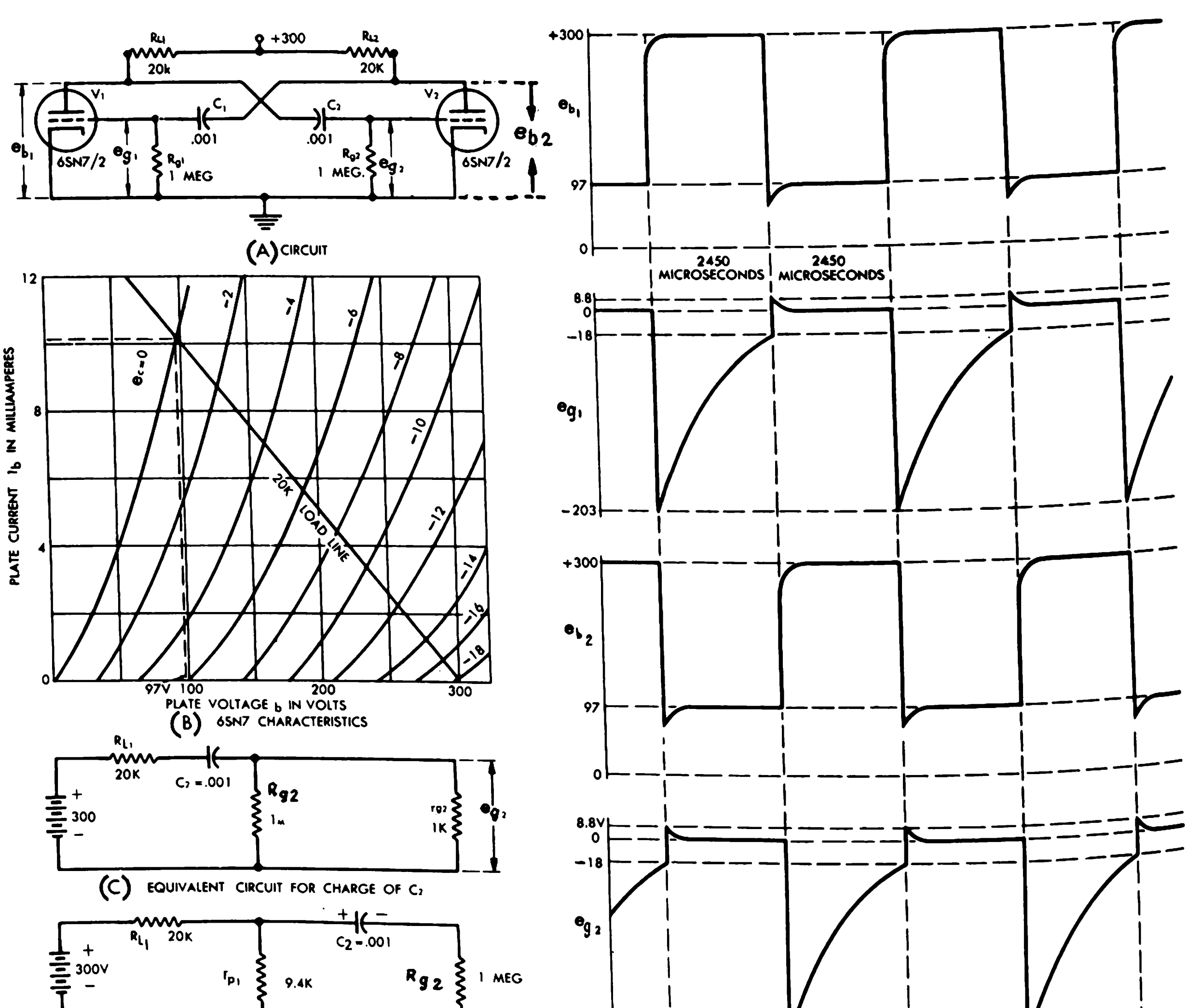

Figure 5-3.—Quantitative analysis of plate-coupled multivibrator.

voltage across r_{p1} (the tube's plate resistance) is 97 volts and the capacitor is discharging from 300 volts to 97 volts. The plate resistance r_{p1} is found by using the plate current and voltage when he grid voltage of V_1 is zero.

$r_{p1} = e_b/i_b = 97/10.3$ ma. = about 9.4K ohms.

n parallel with this (through the battery) is the 0-K plate-load resistor. This parallel combinaion will have a resistance of about 6K and will e in series with the 1-megohm resistor. For implicity this 6-K resistance can be disrearded. This will only introduce an error of less an one percent. The discharge time constant ithout the 6-K resistance will be 0.001 μf. x 1 eg. = 1,000 microseconds.

The discharge continues until the resistor nd grid) voltage at V_2 is just above cutoff. utoff voltage for this tube with 300 volts apied is minus 18 volts as read from the aracteristic curves. The cutoff period is rminated when the voltage drops to 18/203 8.86 percent. The resistor voltage is down to 86 percent in 2.45 time constants. This is lculated from the capacitor discharge curve on e universal time constant chart in figure 4-32. nce the discharge time constant is 1,000 icroseconds, the cutoff time equals 2.45 time nstants multiplied by 1,000 microseconds or 50 microseconds.

The cutoff time for tube V_2 will be 2,450 croseconds. Since the resistor and capacitor ues are exactly the same, tube V_1 will be off for 2,450 microseconds during the other f cycle of operation. The grid and platetage values and curves will also be identical. difference exists in the circuit of each tube, arate calculations must be carried out for h half cycle. In this case, 2,450 + 2,450 ,900 microseconds. The frequency at which are waves are produced is the reciprocal of duration.

$$F = \frac{1}{4{,}900 \times 10^{-6}} = 204 \text{ cycles per second.}$$

The duration and amplitude of the positive on the grid waveform can be readily calted from the equivalent circuit shown in (C) igure 5-3. The positive peak occurs as the citor is charged to a higher plate voltage. acitor charges through resistance that cons of the plate-load resistor for V_1 and the grid-cathode resistance of V_2. This is a total of 21K. The 1-megohm resistor carries only 0.1 percent of the charging current and is therefore safely disregarded. With the 0.001-μf. capacitor the time constant is $0.001 \times 10^{-6} \times 2.1 \times 10^4$ or 21 microseconds. If the charge requires 5 time constants, the positive peak will disappear after a hundred microseconds. The amplitude of the peak can be determined by using Ohm's law. The total voltage rise at the plate of V_1 is 203 volts. This raises the grid voltage from cutoff of minus 18 volts to some positive value. Since the first 18 volts of plate-voltage rise changes the grid voltage to zero, the remaining rise above zero is 203 - 18, or 185 volts. This causes grid current to flow and the voltage to divide across the series combination of the grid-cathode resistance and the plate-load resistance. As the grid-cathode resistance equals 1,000 ohms, and the plate-load resistance equals 20,000 ohms, 1/21 of the 185 volts, or 8.8 volts appear across the grid-cathode resistance. Thus the positive peaks at the grid will be 8.8 volts above zero. Because the plate voltage cannot rise faster than the capacitor can charge, the plate-voltage rise is exponential over a period of 100 microseconds.

This rounds off the leading edge of the plate waveshape. The positive grid at the other tube causes a dip in plate voltage at that tube. The output from this circuit is normally taken from either plate although the grid voltage is sometimes useful.

In the chart (fig. 5-4) showing the effects of varying the sizes of the component parts of this circuit, the essential data is given, but the detailed and less important effects are omitted because of a lack of space. The effects of changing R_{L2}, R_{g2}, C_2, and V_2 are not listed since these effects are similar to those that result from changing R_{L1}, R_{g1}, C_1, and V_1 respectively—except that each effect occurs with the other half cycle of operation.

Synchronization of the Multivibrator

Free-running multivibrators are generally not used as such in electronic circuits because their frequency stability is poor. To avoid this frequency instability, multivibrators are usually synchronized with another frequency which forces the period of the multivibrator oscillation to be exactly the same as the period of

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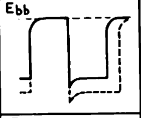
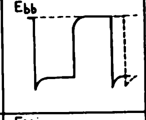
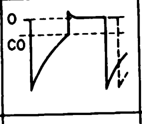
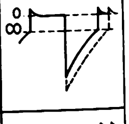
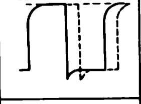
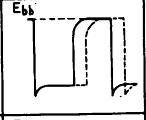
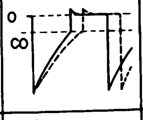
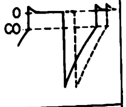
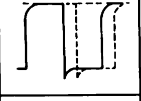
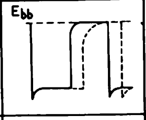
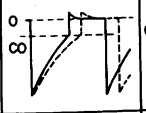
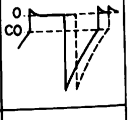
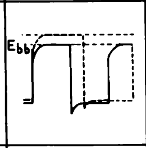
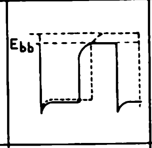
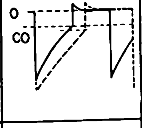
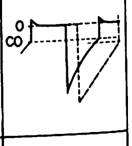
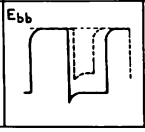
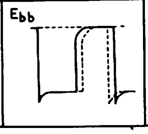
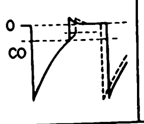
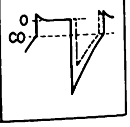
CHANGE	FREQUENCY	AMPLITUDE OF e_{b1}	DURATION e_{b1} AT E_{bb}	AMPLITUDE e_{b2}	DURATION e_{b2} AT E_b	WAVESHAPE CHANGE —— BEFORE CHANGE ------- AFTER INCREASE			
						e_{b1}	e_{b2}	e_{g1}	e_{g2}
$R_{l,1}$ INCREASED	DECREASED. V_2 CUTOFF LONGER.	INCREASED. e_{b1} IS LOWER DURING ZERO GRID VOLTAGE TIMES	UNCHANGED	UNCHANGED	LONGER. GRID IS MORE NEGATIVE AT START OF C.O TIME				
R_{g1} INCREASED	LOWER. V_1 CUTOFF LONGER	UNCHANGED	LONGER. TUBE IS CUT OFF LONGER	UNCHANGED	UNCHANGED				
C_1 INCREASED	LOWER. V_1 CUTOFF LONGER	UNCHANGED	LONGER	UNCHANGED	UNCHANGED				
E_{bb} INCREASED	LOWER. BOTH GRIDS DRIVEN BELOW CUTOFF. CUT OFF VALUE LOWERS SLIGHTLY.	INCREASED. E_b GOES UP. e_{b1} VALUE FOR ZERO GRID VOLTAGE GOES UP SLIGHTLY.	INCREASED. V_1 IS CUTOFF LONGER.	INCREASED. E_b GOES UP. e_{b2} VALUE FOR ZERO GRID VOLTAGE GOES UP SLIGHTLY.	INCREASED. V_2 CUTOFF LONGER.				
V_1 REPLACED WITH TUBE OF HIGHER Mu.	HIGHER	DECREASED. HIGH r_p OF V_1 CAUSED e_{bb} FOR ZERO GRID VOLTAGE TO BE HIGHER.	SLIGHTLY LONGER. CUTOFF FOR V_1 IS LOWER.	UNCHANGED	DECREASED SINCE GRID OF V_2 IS NOT DRIVEN VERY FAR NEGATIVE.				

Figure 5-4.—Effects of varying elements in multivibrator.

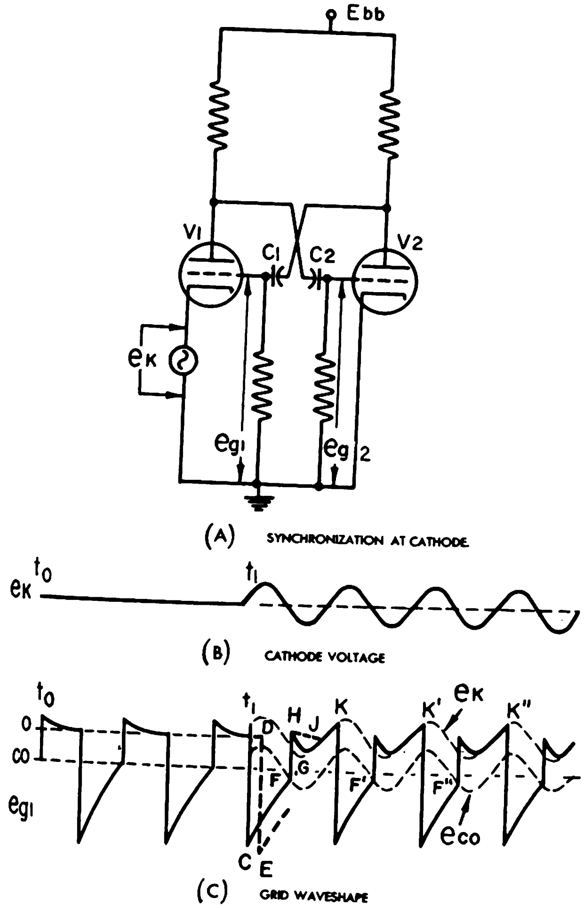
the synchronizing frequency. Such a multivibrator is said to be locked-in by the synchronizing voltage.

SYNCHRONIZATION WITH A SINE WAVE

Although a waveform of almost any shape may be used for synchronization, a sine wave or a pulse is generally used. The circuit of a multivibrator which is synchronized by the injection of a sine-wave voltage in the cathode circuit of one tube is shown in figure 5-5 (A). The actual grid-to-cathode voltage of V_1, which is the voltage controlling the flow of plate current, is the difference between the grid-to-ground voltage e_{g1} and the cathode-to-ground voltage e_k. The source of sinusoidal voltage should have a low internal impedance, otherwise the plate current of V_1 flowing through this source causes a voltage drop which alters the sinusoidal shape of the wave. Sometimes a low-voltage winding on a power-supply transformer, such as a filament winding, is used to supply this control voltage.

If the multivibrator in (A) of figure 5-5 were balanced and running freely, the waveform of the voltage at the grid of V_1 would be that shown between times t_0 and t_1 in (C). Because there is no synchronizing voltage applied between these two times, the cathode voltage will be constant at ground potential as shown in (B). At time t_1, when the synchronizing voltage is suddenly applied, the cathode potential starts to vary sinusoidally. Although this variation does not affect the voltage on the grid with respect to ground, the grid-to-cathode potential contains this sinusoidal component of voltage. Therefore, the effective cutoff voltage of the tube varies sinusoidally about the normal value in phase with the synchronizing voltage on the cathode. The cathode voltage e_k and the effective cutoff voltage e_{co}, shown at (C), explain the synchronizing action by showing that V_1 conducts when the e_{g1} curve crosses the e_{co} curve.

At time t_1 the voltage of the cathode starts to rise, decreasing the conduction of V_1. The positive-going voltage produced at the plate of V_1 initiates the switching action, and the tube is quickly cut off. Thus e_{g1} drops along t_1 instead of DE as it would in the free-running condition. Capacitor C_1 discharges exponentially along curve CFG. Since this curve intersects the e_{co} curve at F, the switching action, by which V_1 is made conducting and V_2 is cut



(A) SYNCHRONIZATION AT CATHODE

(B) CATHODE VOLTAGE

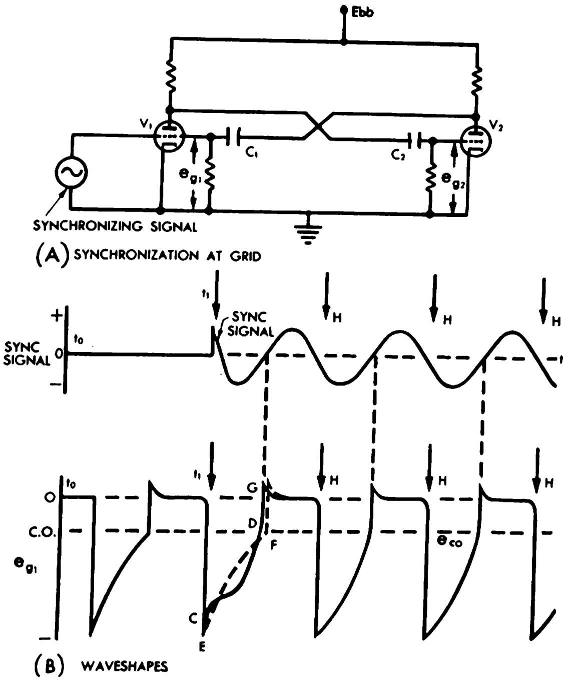
(C) GRID WAVESHAPE

Figure 5-5.—Synchronization with sine wave on cathode.

f, takes place at this time instead of a short me later. Thus the switching takes place at me F instead of at G as would be the case in a ee-running multivibrator. The switching ives the grid of V_1 positive, but the grid rrent drawn, quickly charges C_1 so that the id returns to cathode potential. If e_{g1} fol- wed curve HJ as it would if the multivibrator re free running, the grid would draw current nger, but the synchronizing voltage causes the thode to be negative relative to ground at this ne. Therefore, e_{g1} follows the cathode voltage ng curve HK. When the cathode voltage begins rise the plate current through V_1 starts to crease. By the time K the rise in voltage at plate of V_1, resulting from the decrease in te current, has become large enough to drive into conduction, and the tubes are very rapidly tched.

The cycle of the multivibrator is forced to be somewhat shorter than the length of the free-running cycle by the action of the sine wave. Thus switching in one direction occurs at points F, F', F'', and so forth, and switching in the other direction occurs at K, K', K'', and so forth. The period of the multivibrator, KK' or F' F'', is seen to be equal to the period of the sine wave after the short transition interval; therefore, the multivibrator may be said to be synchronized. A sine wave can thus be used to control the frequency of a multivibrator. The synchronizing voltage can make the multivibrator operate either above or below its natural frequency. However, if an attempt is made to pull the multivibrator to higher and higher frequencies, a limit is reached beyond which the multivibrator synchronizes to one-half of the driving frequency. Similarly, the multivibrator may synchronize to one-third or a smaller fraction of the driving frequency and FREQUENCY DIVISION may be obtained.

When the sine-wave synchronizing voltage is applied to the grid instead of the cathode of one of the tubes of the multivibrator, (fig. 5-6 (A)),



(A) SYNCHRONIZATION AT GRID

(B) WAVESHAPES

Figure 5-6.—Synchronization with sine wave on grid.

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the synchronizing voltage as shown adds directly to the grid voltage. Consequently, the grid-voltage waveform does not resemble that of a free-running multivibrator. Without the synchronizing signal, the multivibrator is free running and the grid waveform appears as shown between t_0 and t_1 in figure 5-6 (B). The synchronizing voltage is applied slightly before time t_1 in the random phase shown, but because of grid limiting, it has no effect until V_1 cuts off at its natural time t_1. Between C and D the synchronizing voltage adds to the normal discharge voltage which would rise along curve EF, and result in the distorted curve shown. Since the synchronizing frequency is higher than the natural frequency of the multivibrator, the distorted curve reaches cutoff sooner than curve EF.

When V_1 is conducting during the time between G and H, grid limiting occurs and prevents the synchronizing voltage from adding to the grid voltage. However, when the synchronizing signal drops below zero voltage and starts to decrease the voltage on the grid, the multivibrator regenerative action rapidly cuts off V_1. Since the action occurs at the same time, H, on each cycle of the synchronizing signal, the multivibrator is forced to operate at the synchronizing frequency. This latter action occurs in this way only when the synchronizing frequency is higher than the natural frequency of the multivibrator.

The first cycle of the synchronizing signal between t_1 and H will not, in general, be the same shape as the steady-state waveshape. The shape of this cycle depends on the time and phase at which the synchronizing signal is applied. The waveshapes in (B) of figure 5-6 show only one of many possible waveshapes for the first cycle. After one or two cycles, however, the multivibrator adjusts itself to a steady-state condition in which it operates so that the phase relation between the synchronizing signal and the multivibrator output is correct.

SYNCHRONIZATION WITH A POSITIVE PULSE

Although multivibrators can be synchronized with a sine-wave voltage, a more satisfactory method of synchronization is obtained by the use of short trigger pulses. An application of this circuit is often found in remote or repeater radarscopes. The sweeps of the PPI are generated by a free-running type multivibrator which is locked in by the trigger pulses derived from the radar transmitter. These pulses may be either positive or negative. Note the effect of positive pulses on the multivibrator grid waveform in figure 5-7. A positive pulse, such as at points B or C, when applied to a tube that is already conducting, serves to cause only a momentary increase in current flow. THUS, A POSITIVE TRIGGER PULSE APPLIED TO A CONDUCTING TUBE OF A MULTIVIBRATOR HAS NO EFFECT ON THE ACTION OF THE MULTIVIBRATOR.

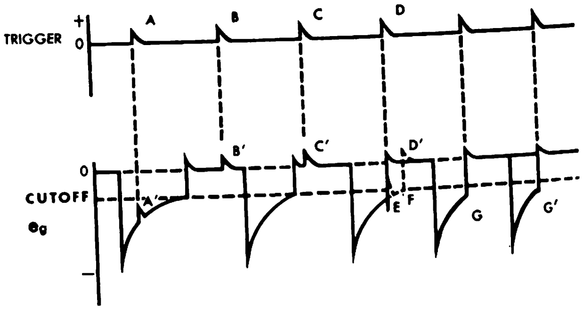

Figure 5-7.—Synchronization with positive pulses on grid.

However, when a positive trigger pulse is applied to a nonconducting tube and is of sufficient amplitude to raise the grid above cutoff, as the pulse at D, the tubes are switched as current starts to flow in the tube which was formerly cut off. If the trigger pulse occurs at a time such as A, the grid voltage will not rise to cutoff as shown at A', and the switching action will not be started. THUS A POSITIVE TRIGGER PULSE APPLIED TO A NONCONDUCTING TUBE IN A MULTIVIBRATOR CAN CAUSE SWITCHING ACTION TO TAKE PLACE ONLY IF THE PULSE IS LARGE ENOUGH TO RAISE THE GRID ABOVE THE CUTOFF VOLTAGE.

With the exception of the trigger pulses, the grid waveform illustrated is that of a free-running multivibrator until time D. The positive pulses which occur at D drive the grid above cutoff, so that the cycle of the multivibrator is shortened by an amount equal to EF. In order for proper synchronization to take place, the period of the multivibrator must be greater than the interval between trigger pulses. Then the trigger pulses cause the multivibrator to switch earlier in the cycle than it would if free-running. As a result, the grid has not reached cutoff by time G when the next trigger pulse is applied. Thus, the frequency of the multivibrator is forced to be the same as the repetition frequency of the trigger pulses, and the multivibrator will be switched consistently at time G after the transition is made from the free-running condition.

SYNCHRONIZATION WITH A SUBMULTIPLE OF TRIGGER FREQUENCY

A multivibrator may also synchronize to a submultiple of the trigger frequency. As shown in figure 5-8, trigger A causes switching of the multivibrator, but triggers B and C have no effect since they are applied when the tube is conducting. Trigger D is applied when the tube is not conducting, but it is not large enough to start conduction so that the next pulse to cause a switching action is trigger pulse E. In the case shown, every fourth trigger pulse switches the multivibrator so that the repetition frequency of the multivibrator is one-fourth of the trigger pulses.

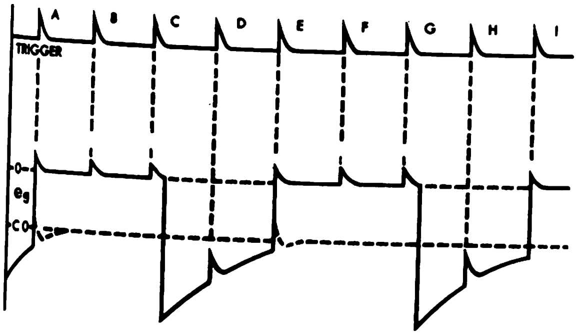

Figure 5-8.—Synchronization at a submultiple of trigger frequency.

By passing the output of this multivibrator through a differentiator, a count-down circuit is obtained. This combination of a submultiple synchronized multivibrator and a differentiator produces one pulse for each four trigger pulses. Other multiples of a pulse count-down may be obtained by changing the RC time constants of the multivibrator.

SYNCHRONIZATION WITH NEGATIVE PULSES

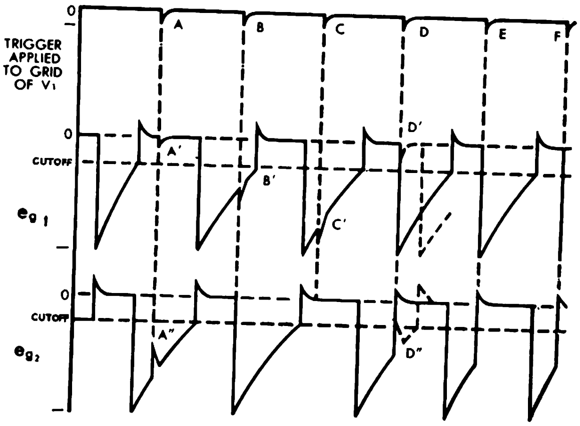

Figure 5-9.—Synchronization at grid with negative pulses.

Negative pulses can be used to trigger a multivibrator as well as positive pulses. As shown in figure 5-9, the first few cycles of the waveforms show the voltage variations that take place at the grids of a free-running multivibrator. As shown at B and B' and at C and C', A NEGATIVE TRIGGER PULSE APPLIED TO A NONCONDUCTING TUBE OF A MULTIVIBRATOR HAS NO EFFECT ON THE OPERATION OF THE MULTIVIBRATOR. However, if the negative trigger pulse is applied to the conducting tube, that tube operates as a single-stage amplifier and applies a larger positive pulse to the grid of the nonconducting tube. The negative trigger pulse A reduces the grid voltage of V_1, as at A', causing an increase in e_{g2}, as at A''. Since the change of e_{g2} is not sufficient to cause switching, trigger pulse A has no effect on the circuit. When a trigger pulse occurs in a later phase relative to the positive alternation of e_{g1}, as at D', the amplified pulse applied to V_2 at D'' raises the grid above cutoff, exactly as if a positive pulse were applied directly. THUS A NEGATIVE TRIGGER PULSE APPLIED TO THE CONDUCTING TUBE OF A MULTIVIBRATOR CAN SYNCHRONIZE THE MULTIVIBRATOR, PROVIDED THE AMPLIFICATION BY THE CONDUCTING TUBE PRODUCES A RESULTANT POSITIVE PULSE LARGE ENOUGH TO RAISE THE GRID VOLTAGE OF THE NONCONDUCTING TUBE TO CUTOFF. Note that it is not necessary for the negative trigger to reduce the grid voltage of the conducting tube to cutoff.

The synchronization voltage can be introduced at the plate as well as at the grid and cathode. The voltage has very little effect on the plate current of the tube to which it is introduced but has the usual effect on the other grid.

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The coupling capacitor transfers the synchronizing voltage to the other grid. Therefore, introducing a pulse of a given polarity at the plate of one tube has the same effect as introducing the pulse with opposite polarity on the grid of the same tube.

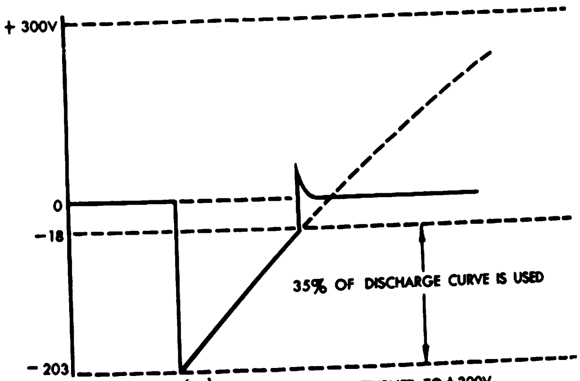
Improving Circuit Action

There are a number of slight changes that can be made in the basic plate-coupled multivibrator circuit to improve its stability and output waveshape. One is to return the grids to a positive voltage, and another is to use series-limiting resistors.

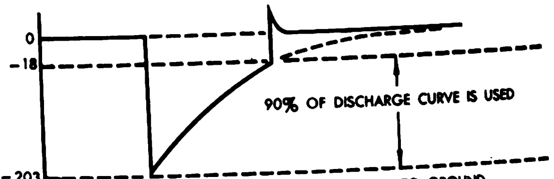
RETURNING THE GRIDS TO A POSITIVE VOLTAGE

Returning the grids to a positive voltage improves the stability of a plate-coupled multivibrator. In this arrangement, the grid-leak resistors are often connected to the source of plate voltage, or the grids are returned to B plus. Under this condition the grid-current flow causes the B-plus potential to exist mostly across the resistor while the grid-to-cathode voltage remains within a fraction of a volt or zero. When the plate voltage of the other tube drops, the capacitor discharges as usual, with a current that is high enough to drive the grid negative by the amount of the plate-voltage drop. Due to this condition the exponential discharge of the capacitor appears as though the capacitor were charged to the plate-voltage drop plus the plate-voltage supply. The net result is that the curve shown in figure 5-10 (A), resulting from the negative peak value to cutoff, is much more linear due to the fact that a smaller percentage of the discharge curve is used.

Returning the grids to a positive voltage produces an advantage in that the discharge curve strikes cutoff at a more nearly vertical angle. This means that if variations of voltage or temperature in the circuit affect the relation of the waveshape to the cutoff value only a small change of time will occur. In contrast, study the grid-voltage curve in (B) of figure 5-10 where the grid resistor is grounded. The discharge curve is almost parallel at the cutoff value. In this case a small variation of the cutoff value will cause a large time change. In conclusion, then, returning the grids to B-plus decreases the CHANGE in duration of pulses and the free-running frequency for a given change in circuit constants.



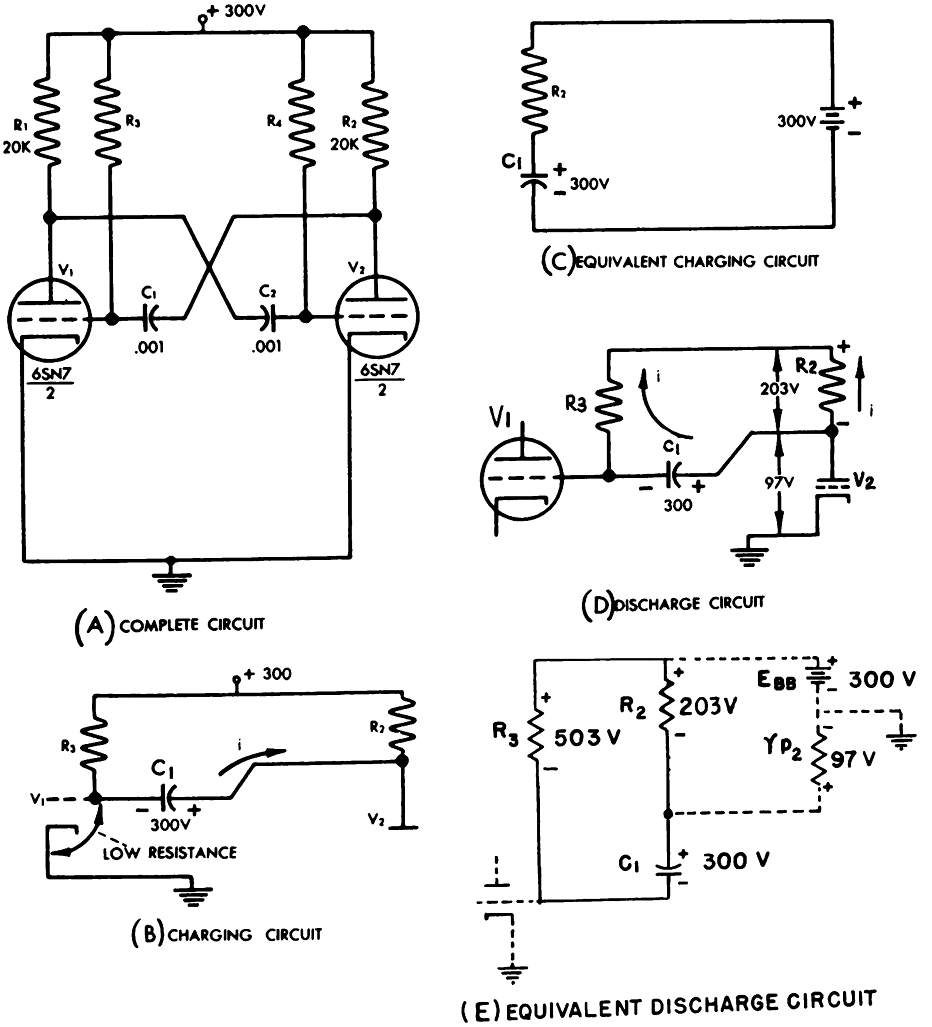
(A) e_{g1} WITH GRID RETURNED TO +300V



(B) e_{g1} WITH GRID RETURNED TO GROUND

Figure 5-10.—Improving the basic circuit.

You can increase your understanding of the effect of returning the grid to B plus by making quantitative analyses and studying equivalent circuits. In figure 5-11 (C), notice the equivalent charging circuit of C_1 during the time that V_1 is conducting. In (B), the parts of the circuit involved during the charge of C_1 are shown. Since the grid-cathode resistance is very small, compared to the grid-leak resistor, it can be represented as a direct connection, producing the equivalent circuit in (C). Here R_2 is relatively small; as a result the capacitor will be fully charged before tube V_2 starts to conduct. Thus, at the time V_1 is cut off, capacitor C_1 has a charge of 300 volts. The discharge circuit for C_1 is shown in (D). V_2 is conducting during this time, causing a voltage of 203 volts across the load resistor R_2. A closed circuit is formed as shown in (E). The voltage across the load resistor may be considered as a source of voltage, or battery, which is of a polarity to aid the capacitor in causing current flow. The total voltage across the resistor R_3 becomes the capacitor charge plus the load resistor voltage (300 + 203 = 503 volts). The grid end of resistor R_3 is 503 volts negative with respect to the end connected to 300 volts. As a result, the grid of



(A) COMPLETE CIRCUIT

(B) CHARGING CIRCUIT

(C) EQUIVALENT CHARGING CIRCUIT

(D) DISCHARGE CIRCUIT

(E) EQUIVALENT DISCHARGE CIRCUIT

Figure 5-11.—Effect of returning grid to B plus.

is 203 volts negative with respect to its iode.

ince the direction of capacitor current is ersed, the plate-voltage source will aid the harge of the capacitor. When a source is ected to a charged capacitor with a polarity discharges it, the capacitor will com- ely discharge and recharge to the new voltage n one long exponential curve. In this case, curve will have the same amplitude as it d if it charged from zero to 503 volts. The lting slope is as shown in figure 5-10 (A). Of se, the slope due to the more rapid dis- ge will go through zero earlier if the same is used. Therefore a longer RC must be when grid resistors are returned to a positive voltage than is used when the resistors are returned to ground, for the same duration of output pulse.

SERIES-LIMITING RESISTORS

The use of series-limiting resistors in the grid circuits of this multivibrator increases the squareness of the waveshapes. In the circuit shown in figure 5-12, these resistors are R_5 and R_6. The first half cycle of the plate and grid waveshapes shown is without the grid-limiting resistors in the circuit, and the second half cycle is with R_5 and R_6 in the circuit. Note that the grid does not go positive when resistors

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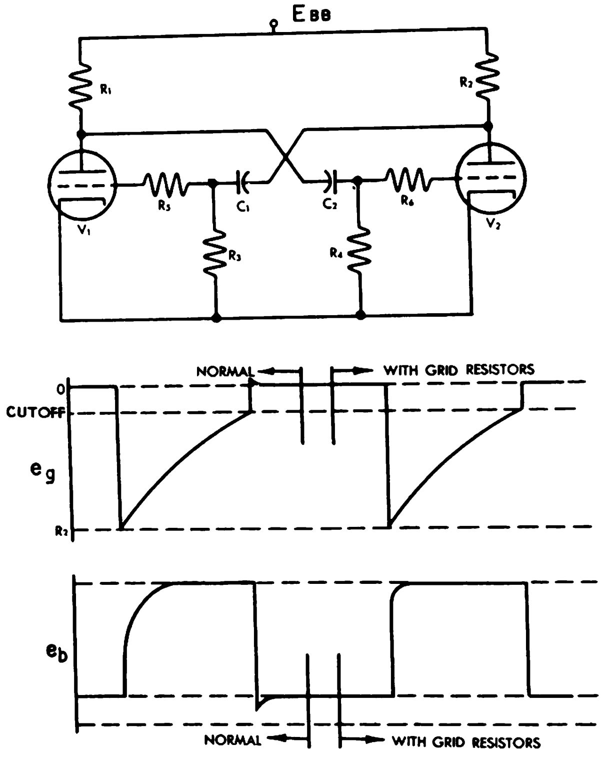

Figure 5-12.—Using series-limiting resistors.

are provided. When the other plate becomes more positive most of the voltage change occurs across the grid-limiting resistor while only a small fraction of a volt exists between the grid and cathode, provided the grid-limiting resistor is of the order of 500K or more. The plate that is going positive cannot normally rise in voltage any quicker than the coupling capacitor can charge. So in the normal circuit, the plate waveshape resembles the coupling capacitor charging curve. When grid-limiting resistors are inserted, the limiting resistor is in series with the low grid-cathode resistance. These two resistors and the grid-leak resistor form a high-resistance circuit for the capacitor to charge through. The circuit is like the trapezoid sweep generator in that a "jump" voltage will occur across the limiting and grid-leak resistors. Then the exponential rise will start from there. In the waveshape of this illustration, the jump is about 90 percent of the total amplitude, with only slight rounding of the leading edge of the pulse.

The Driven Plate-Coupled Multivibrator

You previously saw how the multivibrator circuit can be used either as a free-running or as a synchronized square-wave generator. The circuit can also be used as a monostable or one-shot multivibrator. This is accomplished by holding the circuit inoperative until a pulse is applied to trigger or drive it into operation for one cycle and then return it to the inoperative condition.

The one-shot multivibrator circuit shown in figure 5-13 is the same circuit that you previously studied except that here 50 volts of bias is placed on the grid of V_1. This bias keeps V_1 normally cut off and permits V_2 to conduct continuously. However, the circuit will operate for one cycle if a voltage is applied to the grid of V_1 with sufficient amplitude to raise the grid voltage above cutoff. Since cutoff is minus 18

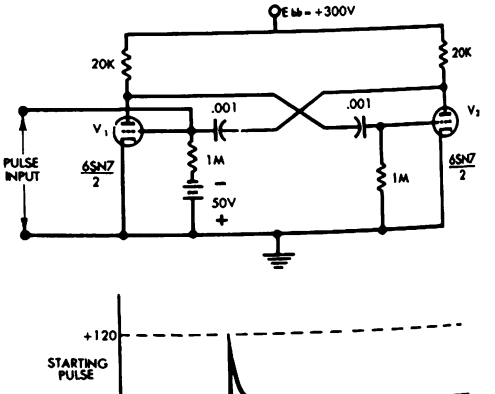

Figure 5-13.—One-shot plate-coupled multivibrator.

volts, the required amplitude must exceed 50 minus 18, or 32 volts positive. Any voltage of more than 32 volts at the grid will cause V_1 to conduct. The resultant drop in plate voltage at V_1 is amplified around the circuit until V_2 is cut off, thus placing the plate of V_2 at supply voltage level. V_2 remains cut off for the usual time and then starts to conduct, driving the grid voltage at V_1 far below cutoff. Because the charge on the V_1 coupling capacitor leaks off to minus 50 volts, which is still below cutoff, the cycle stops as V_1 cannot conduct again. The illustration shows that a positive pulse is applied to the grid to start conduction. One positive square wave is generated at the plate of V_2 for the one pulse. Note in the grid waveshape at V_1 that the V_1 grid voltage starts and ends with minus 50 volts. In order for the circuit to produce another square wave, another pulse must be applied to the grid.

Other methods have been successfully used to keep the driven plate-coupled multivibrator inoperative until pulsed. The circuit in figure 5-14 illustrates one method. This circuit has an advantage over the circuit previously shown in figure 5-13 since a separate power supply is not required. It uses fixed bias provided by a voltage divider from plus 300 volts. With the values shown, the cathode will be 50 volts more positive than the grid. As cutoff is still at minus 18, 32 volts will, as before, be required to make the tube conduct. When conduction starts due to a pulse on the grid, the circuit will oscillate for one cycle, and then quit.

A negative pulse can be used to start a cycle in either of the last two circuits illustrated provided it is introduced at the plate of V_1 or the grid of V_2. This causes the negative pulse to be amplified and inverted by V_2 bringing the grid of V_1 above cutoff and thereby starting tube operation.

Bistable Multivibrator

A modification of the basic plate-coupled multivibrator will give a circuit that has two stable states. Two variations of this circuit are shown in figure 5-15. They are similar to the previously discussed plate-coupled circuit (figs. 5-13 and 5-14), except that a negative bias is applied to the grids of both tubes. This new arrangement requires a separate trigger pulse for each half cycle of operation.

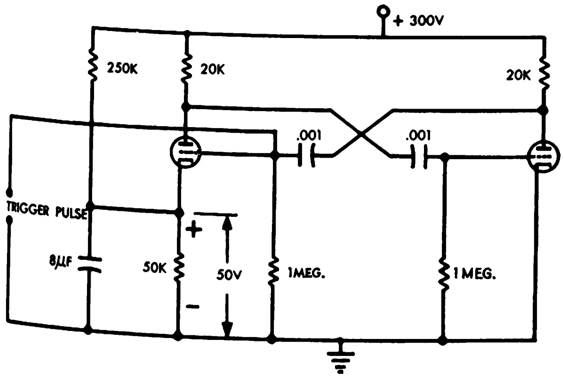

Figure 5-14.—One-shot plate-coupled multivibrator.

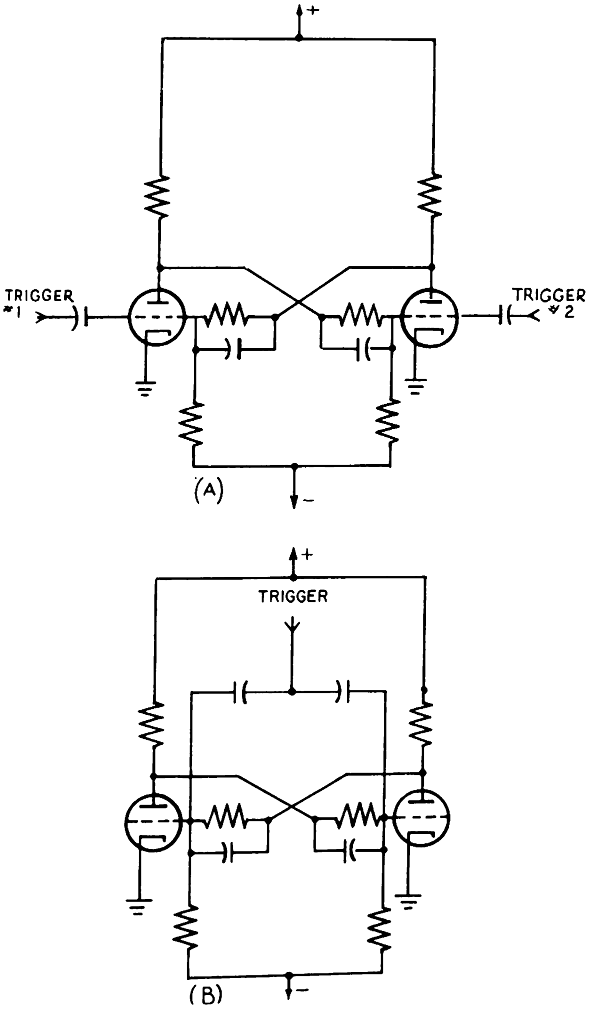

Figure 5-15.—Flopover and scale-of-two multivibrators.

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In the flopover circuit, shown in figure 5-15 (A), trigger pulses from different sources are applied to each grid. Once a trigger from one source has caused the circuit to flopover, it then requires a trigger from the second source to generate the other half cycle. In other words, the flopover circuit responds to alternate triggers from the two sources. This type of circuit may be used in the formation of a gate, which has the leading edge formed by a trigger from one source and the trailing edge formed by the trigger from the second source.

The scale-of-two circuit shown in figure 5-15 (B) has trigger pulses applied to both grids from a single source. Each pulse drives the circuit from one stable condition to the other. As in the previous flopover circuit, two trigger pulses are needed to generate each complete cycle. The scale-of-two circuit is sometimes referred to as the BINOMIAL-COUNTER. By using a cascaded group of scale-of-two circuits a scale of four, eight, sixteen, etc., circuits are possible. In other words one pulse will be derived for each four, eight, sixteen, etc., pulses put into the circuit. The scale-of-two circuit is also used for time sharing in video relays. In this case the gate from one tube of the multivibrator is used to turn one video amplifier on and off on alternate pulses and the output from the other multivibrator tube turns a second video amplifier tube on and off at opposite alternations.

The Cathode-Coupled Multivibrator

In the plate-coupled multivibrator, feedback in the correct phase to sustain oscillation was obtained by connecting the plate of each tube to the grid of the other. Feedback in the correct phase can also be obtained by connecting the two triodes as shown in the cathode-coupled multivibrator of figure 5-16. The usual plate-to-grid connection in this case is made from V_1 to V_2, and the cathode of the second tube is capacitively coupled to the cathode of the first. If you follow through these changes, you can see that feedback is in phase. Assume that the current in V_1 is decreasing. As the plate becomes more positive, the V_2 grid will become more positive and current will increase in V_2. This makes the cathode of V_2 more positive. Since the cathode of V_1 is coupled to the V_2 cathode, the cathode of V_1 will become more positive. Because a positive-going cathode is like a negative-going grid, the current in V_1 will decrease. Since the original change was a current decrease in V_1 the feedback is in phase to sustain oscillation.

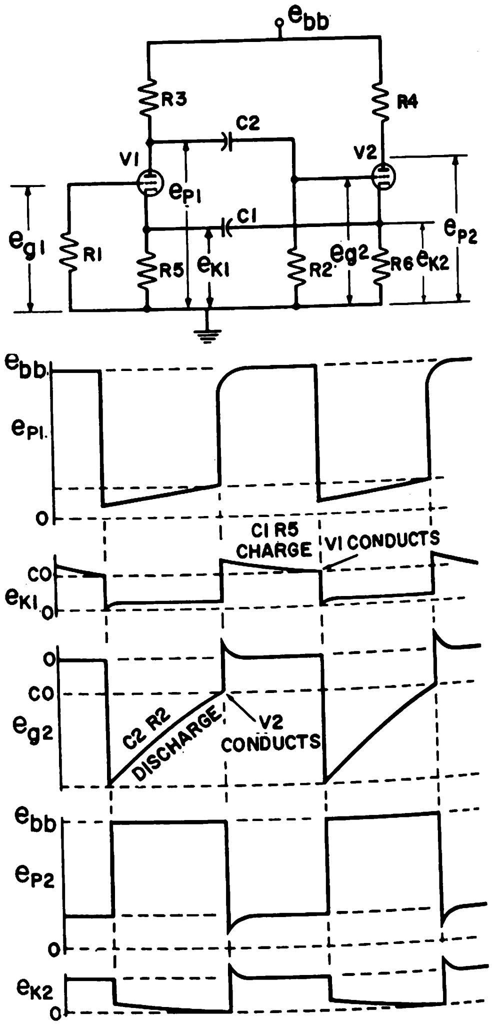

Figure 5-16.—Cathode-coupled multivibrator

Notice that in this multivibrator the cutoff time of the grid of the second tube is controlled by the discharge of C_2 through R_2, while the cutoff time for the first tube is controlled by the charge of the cathode coupling capacitor through the cathode resistor of the first tube.

In order to understand the operation of this multivibrator, assume that V_1 is conducting and that V_2 has been cut off by an action similar to that just described. Capacitor C_2 discharges through R_2, R_5, and r_p of V_1, so that the voltage at the grid of V_2 decreases from a high negative potential toward ground as the discharge current through R_2 decreases. When e_{g2} rises to the cutoff voltage of V_2, the tube starts to draw current through R_6. The rising voltage produced across this resistor is coupled through C_1 to the cathode of V_1 since the voltage across the capacitor cannot change instantaneously. The positive-going voltage which is coupled to the cathode of V_1 adds to the existing voltage across R_5, reducing the flow of current in V_1. As i_{p1} decreases, the voltage at the plate of V_1 increases, and this positive-going voltage is coupled to the grid of V_2 to further increase the current in V_2. This action around the circuit is regenerative, and it ends with the current in V_1 reduced to zero and the current in V_2 at a maximum.

Capacitor C_1 is charging toward the voltage existing across R_6 through the path R_5, r_p of V_2, and R_4 to the high-voltage supply. The charging current produces across R_5 a voltage which is more than sufficient to hold V_1 beyond cutoff. However, as the voltage across the capacitor rises, the magnitude of the charging current falls. Consequently, the voltage across R_5 decreases and at some time it will fall below the value required to cut off V_1. At this instant, a current starts to flow through V_1, lowering the voltage at the plate of the tube. This negative-going voltage is coupled through C_2 to the grid of V_2, causing i_{p2} to decrease. As a result of the reduction of i_{p2} and the decrease in e_{k2}, the voltage across R_5 decreases. Therefore, C_1 discharges through r_p of V_1, R_3, and R_6 in an effort to charge in the opposite direction to the voltage across R_5. The cumulative effects of the discharge of C_1 through R_6 and the negative-going voltage applied to the grid of V_2 combine to cut off V_2 almost instantaneously.

The waveshape at the important points are shown in figure 5-16. While V_1 is cut off, a cathode voltage exists due to the charge of the cathode-coupling capacitor. The voltage is visible in the waveshape e_{k1}, as the high initial charging current causes a high cathode voltage. At a certain positive cathode voltage the grid-to-cathode voltage difference will be so great that no plate current will flow. The cathode voltage exceeds this value at first, but as the capacitor charges, the resistor (R_5) voltage decreases exponentially until the cutoff value is reached. At this instant current flows in V_1, which, by the drop in e_{p1}, cuts off V_2. The discharge of C_2, holding e_{g2} below cutoff, is the usual action as observed with the previous circuit. When V_2 is cut off, its plate voltage rises instantly to E_{bb}, forming a square waveshape. There is no rounding of the corner because there is no capacitor to charge. When V_2 is cut off, the cathode voltage tends to become zero, but it cannot be zero until C_1 is discharged. Therefore, the waveshape shows first a sudden drop as plate current ceases, then an exponential drop as the capacitor discharges. The same discharge is indicated by the plate and cathode waveshape of V_1. The discharge is such that it makes the cathode of V_1 more negative, so the plate voltage drops below the zero grid-voltage level. As the discharge progresses, capacitor voltage decreases and the effects of it decrease. The plate voltage gradually rises and a slight rise of cathode voltage is seen.

Generally speaking, increasing the size of any part in the circuit except R_1 will lower the frequency. The duration of each half cycle is dependent upon every part in the circuit. Changing any one value will affect the duration of both half cycles. Increasing the power supply voltage will also lower the frequency.

Because of the instability of this circuit when free running, it should be synchronized if it is to operate at a constant frequency or if its action is to be simultaneous with the action of some other circuit. Like the plate-coupled multivibrator, this circuit can be synchronized at either plate, grid, or cathode if the right polarity of synchronization voltage is used. If, for example, you should desire to start conduction in the second tube at a certain time, a positive voltage should be applied to the second grid, first plate, or first cathode at that time. A negative pulse is required at the first grid, second plate, or second cathode to do the same thing. This circuit can also be kept normally inoperative and be made to operate only once for each trigger pulse.

The Cathode-Coupled Monostable Multivibrator

A widely used circuit, which never becomes free running and must always be triggered for each output pulse is the one-cycle or cathode-coupled monostable multivibrator (sometimes referred to as a one-shot or single-kick multivibrator). As shown in figure 5-17, the circuit consists essentially of a two-stage resistance-capacitance-coupled amplifier with one tube cut off and the other conducting normally. The

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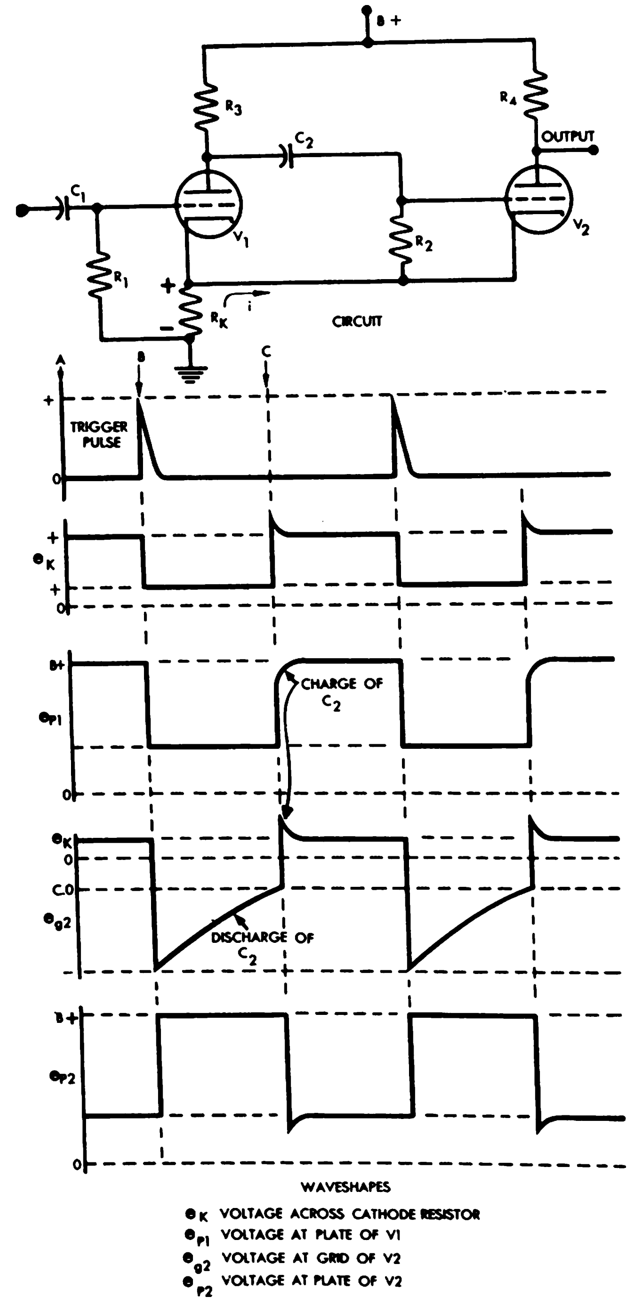

Figure 5-17.—Cathode-coupled monostable multivibrator.

balanced condition of the circuit is established by the arrangement for biasing the tubes. The grid of V_2 is connected to its cathode through the resistor R_2, thus it conducts quite heavily, and the resultant voltage drop across R_k, due to V_2 conducting, biases V_1 to cutoff. When V_2 is not conducting, V_1 cannot be cut off by the self-bias developed across R_k.

The steps in the action of the cathode-coupled monostable multivibrator are as follows:

1. V_1 is cut off initially by the voltage drop produced across R_k by i_{p2}, the plate current of V_2 (time A).
2. V_2 is conducting heavily because its grid is at its cathode potential (time A).
3. A positive trigger pulse (time B) sufficient in amplitude to raise the grid of V_1 above cutoff voltage, is impressed on the grid of V_1 through C_1.
4. V_1 begins to conduct and its plate voltage decreases. This decrease passes through C_2, as the voltage across a capacitor cannot be changed instantaneously, and appears on the grid of V_2 as a negative-going voltage.
5. The negative-going voltage on the grid of V_2 decreases i_{p2}.
6. The voltage drop across R_k decreases, allowing more current to flow in V_1.
7. The plate voltage of V_1 is still further decreased.
8. The grid of V_2 goes more negative.
9. This action is repeated until V_2 is cut off and then V_1 is conducting heavily. The switch from V_2 to V_1 is practically instantaneous.
10. V_2 begins to conduct (time C) because the charge on C_2 has decreased to cutoff.
11. The plate current of V_2 flowing through R_k, raises the cathode voltage of V_1, thus reducing its plate current.
12. The decreased plate current of V_1 allows the plate voltage of V_1 to increase.
13. This increase is coupled to the grid of V_2, increasing still further its plate current.
14. The action described is repeated until V_1 is cut off and V_2 is conducting heavily. This action also is practically instantaneous.

The circuit has now come back to its original balanced state and will remain so until another positive pulse arrives and causes V_1 to conduct. When applied to the input of the monostable multivibrator, every positive trigger pulse which causes V_1 to conduct results in a large positive-pulse output from the plate circuit of the second tube. The length of the positive-output pulse produced at the plate of V_2 is controlled by the time constant of C_2 times R_2. If larger values of C_2 and R_2 are used, the length of the positive utput is increased. A positive-output voltage ulse is produced for each positive-input trigger ulse.

UANTITATIVE ANALYSIS

The quantitative determination of the ampliude and duration of the output pulse is not too ifficult to accomplish. (See fig. 5-18.) The ircuit shown is the most basic one. The wavehapes are similar to those in figure 5-17 except hat the voltages and time intervals have been etermined and the waveshapes drawn to scale.

Start by finding the voltages in the circuit efore the trigger pulse arrives. Check to see hat the 3-K resistor has V_1 cut off. The circuit vill not work if R_k is too small. V_2 is conducting ue to zero bias. Now draw a loadline on the characteristic curve to find the voltages. In drawing the loadline, consider the cathode resistance. Any resistance in series with the tube will affect the current, but if the cathode resistor is quite small, its effect is negligible. You can obtain reasonably accurate results by disregarding the cathode resistance when it is less than 10 percent of the load resistance. When it is 10 percent or more, sketch the loadline for the total cathode and load resistance. In the case of V_2 in this problem, the cathode resistance is exactly 10 percent of the load resistance; so the loadline is drawn for 30K + 3K = 33K. Check the plate current and plate voltage at the intersection of the loadline and zero grid bias. The plate voltage appears to be 73 volts and the current 6.9 ma. Knowing the current through R_k, find the voltage across it.

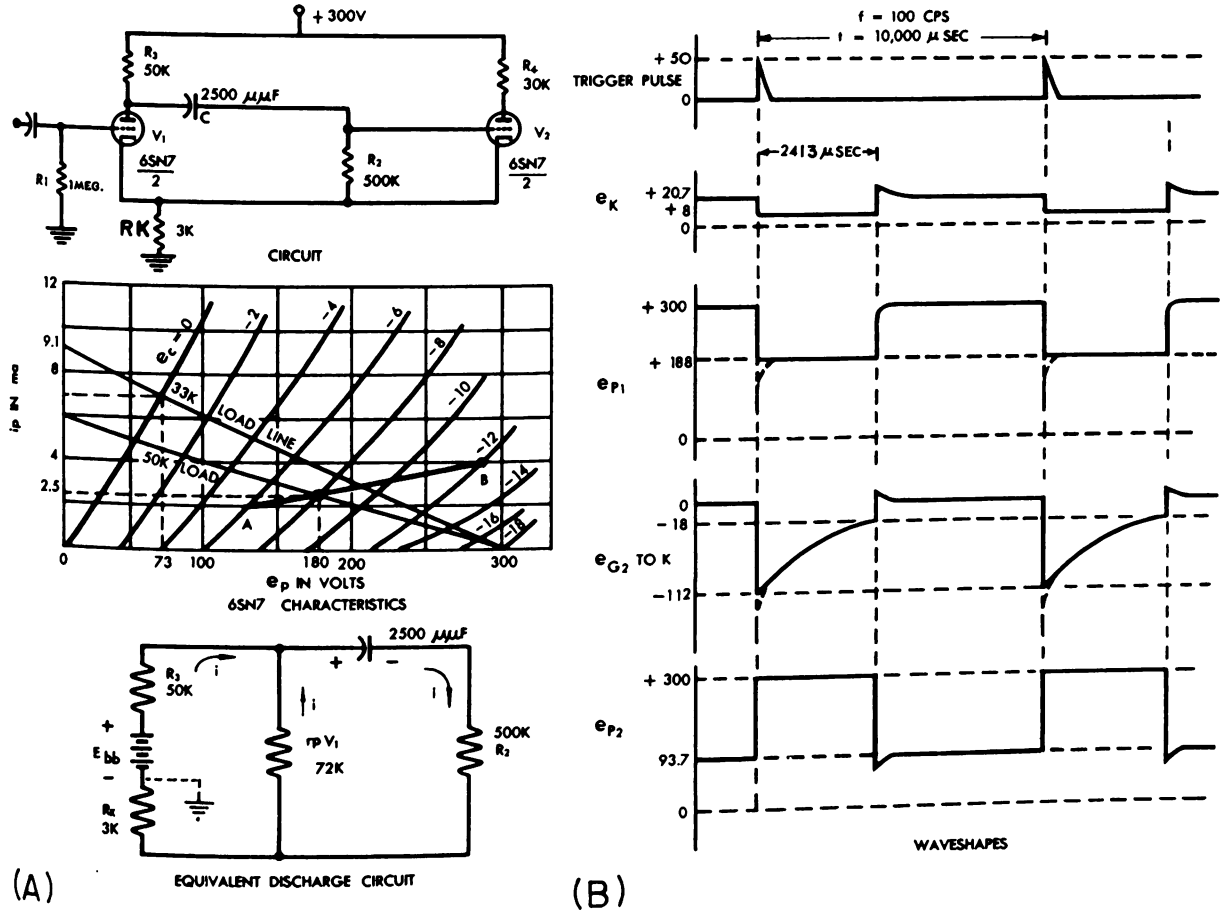

Figure 5-18.—Quantitative analysis of cathode-coupled monostable multivibrator.

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($E = IR$, $i_pR_k = 0.0069 \times 3{,}000 = 20.7$ volts.) Cutoff is 18 volts, as read from the curves, so the first tube is actually cut off, and the circuit will function.

Now proceed with the calculations. The waveshape shown is the plate-to-ground voltage while the characteristic curves show plate-to-cathode voltage. So you must add the cathode voltage above ground to the plate voltage to find the actual plate-to-ground voltage. Since the cathode is 20.7 volts above ground, add this to 73 to get 93.7 volts at the plate of V_2. To simplify the picture, the waveshape at the grid of V_2 shows the voltage at the grid with respect to the CATHODE rather than ground. In the waveshape of cathode voltage shown, notice that before the trigger pulse arrives, the cathode voltage is 20.7 volts as previously calculated.

Now, determine the voltages in the circuit immediately after the trigger pulse and switchover has occurred. During this time, the second tube is cut off so the plate voltage there is 300 volts. The first tube is conducting as much as a self-bias 3-K resistor will allow. To find this value, a loadline and bias line are required. Since 3K is less than 10 percent of 50K, the loadline can be drawn for 50K only. For the bias line, assume different values of current, find the bias, and plot the points on the characteristic curves. For example, if the current is 2 ma., the bias would be i_pR_k, or $0.002 \times 3{,}000$, or 6 volts. To plot this, find the 2 ma. current line and the 6-volt grid-voltage curve (point A). Assume a second current of 4 ma. The bias is 12 volts if 4 ma. flows through the 3-K resistor. Mark the intersection of the 4 ma. current line and 12 volts grid-voltage line (point B). Draw a line through these points and where the bias line intersects the loadline is the operating point for the tube. According to the illustration, it appears that the bias or cathode voltage is 8 volts. The plate-to-cathode voltage is 180 volts. So the plate voltage has changed from 300 to 180 plus 8, or 188 volts. The change is 112 volts in the negative direction. The capacitor must discharge by this amount through the 500-K grid resistor R_2. The new plate voltage at V_1 is shown on the e_{p1} curve.

The grid voltage at V_2 goes from zero to negative 112 volts at the switchover time, then decreases exponentially toward zero. This holds V_2 nonconducting until the voltage decreases below cutoff. From the curves, cutoff is minus 18 volts. In order to calculate the time of this exponential decrease, the RC must be known. C is given as 2,500 μμf. The grid resistor of 500K can be considered as the total R for approximate calculations, but the current flows through the 500-K resistor, then through two parallel paths in returning to the capacitor. One path is through R_k, the power supply and R_3 in series. The other path is through the tube. Assuming the internal resistance of the power supply is zero, the first path has a resistance of 53K. The other parallel path, through the tube, has a resistance which is somewhat variable due to bias change during the discharge, but is quite near the value determined by dividing the plate voltage by the plate current. From the curves, the plate voltage is 180 volts, the plate current 2.5 ma., both at the operating point with 8 volts bias. Since $r_p = e_p/i_{p1}$, the tube resistance is 180/0.0025, or 72K. This parallel combination (with a net resistance of 30.5K) is in series with the 500-K resistor to form an equivalent circuit as shown in the equivalent discharge circuit. From this equivalent circuit you can see that the values for determining time constant are as follows:

$$
\begin{aligned}
e_{g2}\text{ cutoff} &= -18 \text{ volts}\\
e_{g2}\text{ max. neg.} &= -112 \text{ volts}\\
R &= 530.5\text{K}\\
C &= 2{,}500\ \mu\mu\text{f.}
\end{aligned}
$$

The capacitor will discharge from minus 112 volts to minus 18 volts, which represents a drop of 112 minus 18, or 94 volts. The percentage of discharge equals 94/112 or 84 percent, thus the capacitor will have 100 minus 84 or 16 percent of full charge left when V_2 starts to conduct. From the universal time constant chart (fig. 4-32), for 16 percent of full charge it is found that 1.82 RC's are required. One RC = 530.5K x 2,500 μμf. or 1,326 microseconds. Then 1.82 RC's = 1.82 x 1,326 = 2,413 μsec. The positive square wave at the second plate will have a duration of 2,413 microseconds and its amplitude will be 300 minus 93.7, or 206.3 volts.

The circuit switches over again at the end of 2,413 microseconds. V_2 conducts, raising the cathode voltage to 20.7 volts, cutting off V_1. The plate voltage of V_1 goes to 300 volts as fast as the capacitor can charge. The capacitor charging current raises the grid of V_2 to a positive voltage momentarily and the cathode above 20.7 volts momentarily. This in turn causes a momentary dip in the plate voltage at V_2. The amplitude and duration of these momentary harges can be calculated by using the same rocedure outlined for the plate-coupled multiibrator.

A trigger pulse of a large voltage will cause he dip shown by dotted lines in the waveshape of V_1 plate and V_2 grid in figure 5-18. This dip is n amplified version of the trigger pulse and asts no longer than the trigger pulse. It does not ffect the discharge time of the capacitor. If the ulse is of the minimum amplitude required to rigger this circuit, this dip will hardly be oticeable. Experience has shown that the trigger pulse should be of the lowest possible amplitude consistent with reliable operation.

The duration of the output pulse can be varied rom time duration of the trigger pulse to the ime between pulses. If attempts are made to nake the pulse longer than the time between ulses, the second pulse may not start a new ycle, and the circuit would operate on every ther trigger pulse, and count-down would occur.

EFFECT OF VARYING CIRCUIT ELEMENTS

The usual method of varying the output pulse width is to vary the size of the RC in the grid of V_2. The pulse width will increase with the resistance of R_2 and the capacity of C. Another result is that the amplitude of the output pulse will increase with an increase of the plate-load resistor. Notice these effects in the chart in figure 5-19 which summarizes the effects of varying the circuit elements in the monostable multivibrator.

The stability of the pulse width from this circuit is improved by returning the grid of V_2 to B plus. The capacitor discharges at a higher and more nearly linear rate below the cutoff value, causing the slope to be steeper at cutoff.

Although the trigger pulse is applied to the first grid in this circuit, the circuit can also be triggered at the plate of the first tube or the grid of the second tube if a negative pulse is used. The action will be the same.

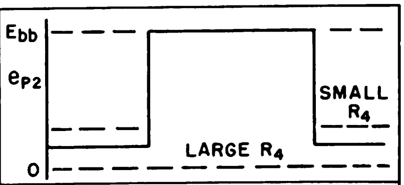
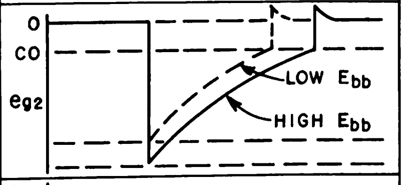
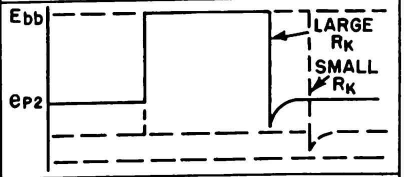
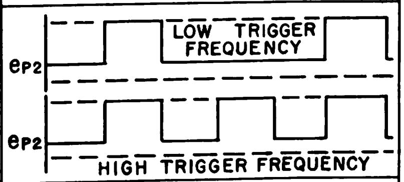
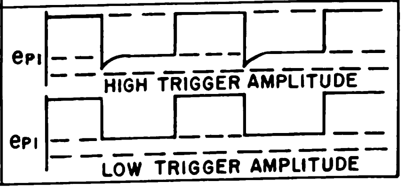
INCREASE R_4	NO CHANGE DOES NOT APPRECIABLY EFFECT PRECEDING CIRCUIT	INCREASED e_{p2} DROPS TO LOWER VOLTAGE	NO CHANGE	NO CHANGE	
INCREASE E_{bb}	INCREASED BECAUSE V_1 PLATE SWING AND V_2 GRID VOLTAGE CHANGE IS GREATER	INCREASED DUE TO GREATER V_2 PLATE VOLTAGE CHANGE	NO CHANGE	DECREASED SLIGHTLY, LARGER PERCENTAGE OF DISCHARGE CURVE USED	
INCREASE R_k	SHORTER SINCE VOLTAGE CHANGE AT PLATE OF V_1 WILL BE DECREASED	DECREASED DUE TO LESS V_2 PLATE VOLTAGE	NO CHANGE	INCREASED BECAUSE VOLTAGE CHANGE ACROSS C WILL BE DECREASED	
INCREASE TRIGGER FREQUENCY	NO CHANGE UP TO POINT WHERE DURATION IS TIME BETWEEN PULSES	NO CHANGE	INCREASED	NO CHANGE	 e_{p2} LOW TRIGGER FREQUENCY e_{p2} HIGH TRIGGER FREQUENCY
INCREASE TRIGGER AMPLITUDE	NO CHANGE	NO CHANGE	NO CHANGE	SMALL INCREASE WILL IMPROVE STABILITY IF ORIGINALLY TOO LOW	 e_{p1} HIGH TRIGGER AMPLITUDE e_{p1} LOW TRIGGER AMPLITUDE

Figure 5-19.—Varying elements in monostable multivibrator.

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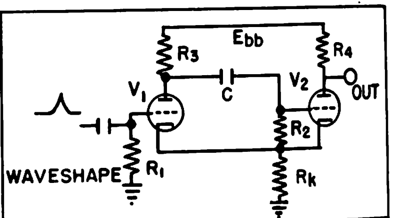
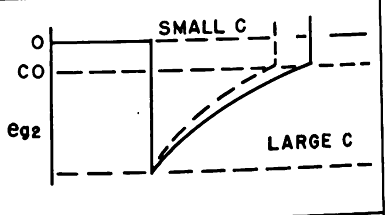
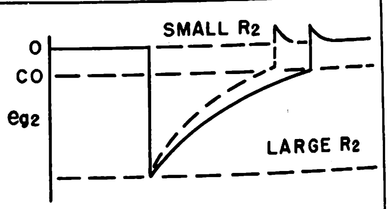
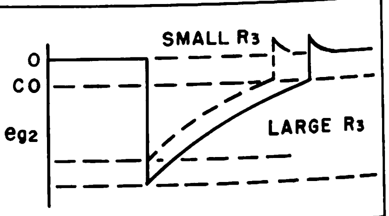
CIRCUIT CHANGE	EFFECT ON DURATION OF OUTPUT PULSE	EFFECT ON AMPLITUDE OF OUTPUT PULSE	EFFECT ON FREQUENCY OF PULSE REPETITION	EFFECT ON STABILITY	 Ebb R3 R4 V1 C V2 OUT R2 WAVESHAPE R1 Rk
INCREASE C	INCREASED BECAUSE DISCHARGE LASTS LONGER	NO CHANGE	NO CHANGE FREQUENCY GOVERNED BY TRIGGER FREQUENCY	NO CHANGE SAME PERCENTAGE OF RC USED	
INCREASE R_2	INCREASED DISCHARGE IS SLOWER	NO CHANGE	NO CHANGE	NO CHANGE SAME PERCENTAGE OF RC USED	
INCREASE R_3	INCREASE BECAUSE AMPLITUDE OF e_{g2} IS INCREASED	NO CHANGE	NO CHANGE	DECREASED BECAUSE DISCHARGE CURVE HAS LESS SLOPE AT CUTOFF	

Figure 5-19.—Varying elements in monostable multivibrator—Continued.

The monostable multivibrator (fig. 5-20) is used in a radar set to produce a pulse of measured duration which drives a sawtooth sweep generator. The basic circuit is modified several ways to produce this more efficient circuit. A third tube is incorporated in the circuit to isolate the multivibrator from the source of trigger voltage and to amplify and sharpen the pulse. This third tube (V_3) is biased beyond cutoff so that it acts as an open circuit at all times except when a trigger pulse is on the grid. The grid of the first tube (V_1) has about plus 14 volts on it from the plus 300-volt voltage divider, while the grid of the second tube (V_2) is returned to plus 300 volts through a large resistor. The current through V_2 and the cathode resistor is high enough to cut off the first tube in spite of the positive voltage on V_1 grid. This positive voltage partly determines the duration of the output pulse. The circuit operates in this way—a positive trigger pulse, simultaneous with the transmitter pulse, is applied to the grid of V_3. This tube is called a CLIPPER since a 22-volt bias keeps it cut off and only the peak of the trigger pulse causes conduction. Due to amplification in V_3, a large negative-going charge appears in the plate circuit. This is coupled through the 0.03-μf. capacitor to the grid of V_2. The current in V_2 is reduced, V_1 conducts, the added drop cuts off V_2, and the discharging capacitor keeps V_2 cut off.

When the capacitor discharges down to cutoff for V_2 this tube would conduct, ending the output pulse. However, this is the sweep circuit and the pulse should end when the spot reaches the range mark for maximum range. So a voltage is fed back to this multivibrator at the time the spot reaches the last range mark. This voltage is a negative pulse, applied to the grid of V_1. This reduces the current in V_1, and the small change is amplified around the circuit to cut off V_1 and causes V_2 to conduct again. Dotted lines in the V_2 grid waveshape show the normal changeover time, which is always later than the sweep-stop

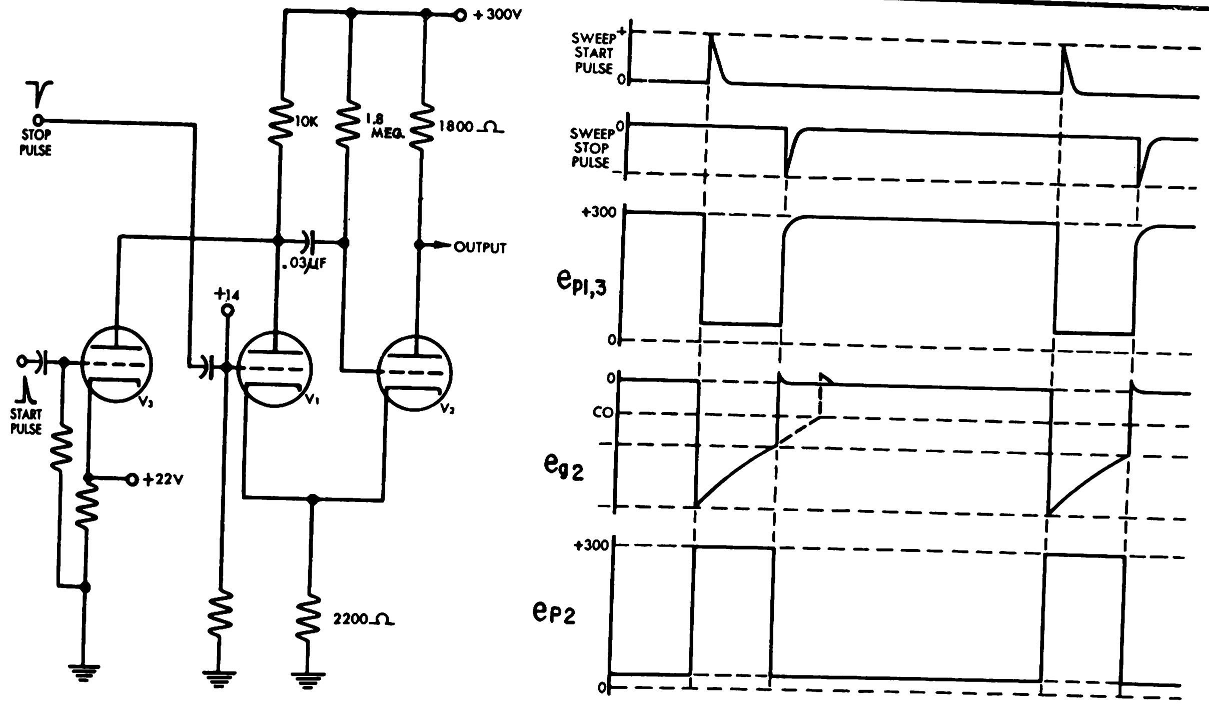


Figure 5-20.—Application of monostable multivibrator.

ulse. This system of stopping the sweep
ultivibrator with a voltage from the sweep de-
ection circuits simplifies the adjustments in the
weep circuit. When the range switch is posi-
oned to change the duration of the sweep, no
rt of this multivibrator is changed. But the
eed of the spot movement is changed so it
eaches the last range mark at a different time
d the stop-pulse cuts off the multivibrator
a different time. Thus, the duration of the
lse is determined by the sweep circuit rather
an the constants of the multivibrator circuit.

You recall that a hard-tube sawtooth genera-
must be driven with a negative square wave
its grid. The positive square-wave output
om this monostable multivibrator is amplified
l inverted by a triode amplifier, then is ap-
ed to the sweep-generator tube in the normal
y.

E AS A DELAY CIRCUIT

In addition to producing pulses of a certain
ation, the monostable multivibrator is some-
es used to "delay" a pulse. For example, in
radar set, the process of causing the transmitter to operate consumes about 5 microseconds, and the transmitter pulse occurs 5 microseconds after the original trigger pulse. While the sweep voltage in the indicator circuit must start at the same time as the transmitter pulse, the original pulse is used for the sweep voltage so that both the sweep and transmitter pulses occur at the same frequency. However, since the original synchronization pulse would start the time base 5 microseconds before the transmitter operates, it cannot be used directly. Instead, it must be "delayed" 5 microseconds. The monostable multivibrator can introduce the delay. The usual multivibrator circuit is used, with a transformer input, as shown in figure 5-21. The input pulse is negative and occurs five microseconds before the transmitter signal. Due to the transformer connections, the polarity is reversed and the circuit is triggered by the resulting positive pulse. The usual square wave appears at the second plate, with the duration accurately measured by the RC circuit at the grid. The output transformer, T_2, features a short L/R time constant, so the square wave is differentiated in the secondary. Again by selecting proper secondary connections, the second peak can be made negative.

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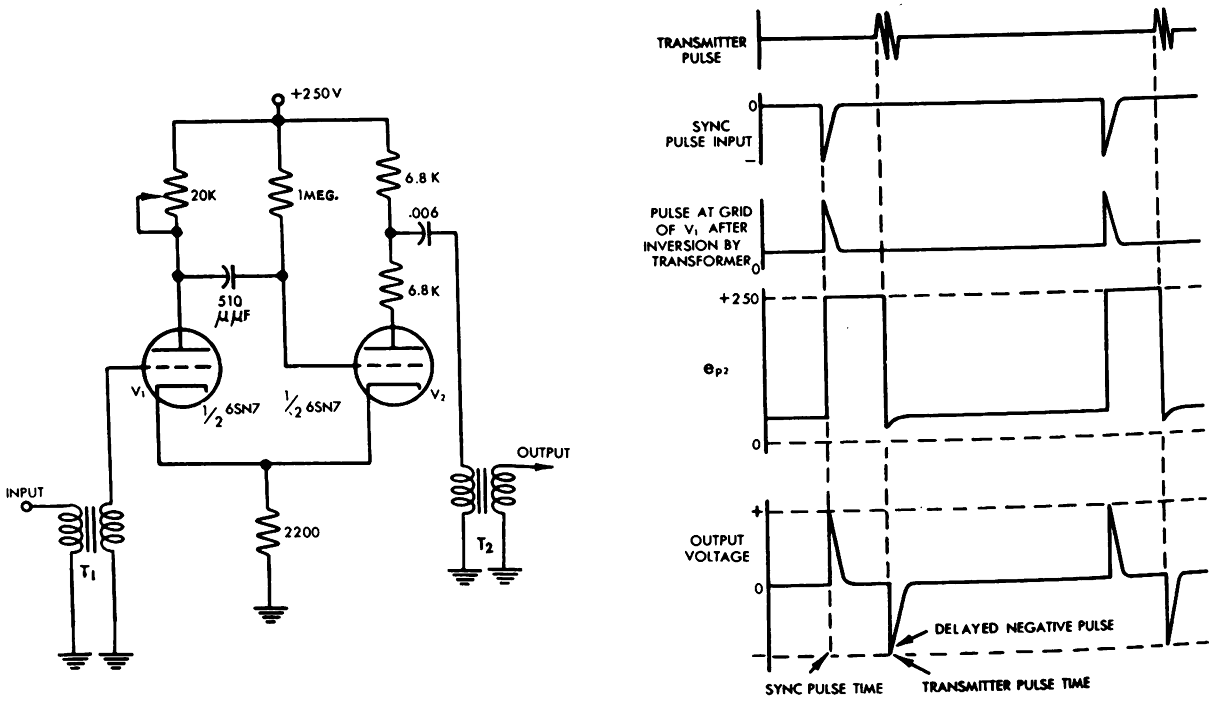

Figure 5-21.—Monostable multivibrator as delay circuit.

So the original negative peak is replaced by a similar negative peaked pulse which is delayed 5 microseconds. The delay need only be adjustable over a narrow range, so the plate-load resistor of the first tube is variable.

The Phantastron Circuit

The phantastron is another circuit which is used to delay a timing pulse. It is classed as a medium precision delay circuit. Its operation and output are very similar to those of the monostable circuit. Under power supply voltage changes it is quite stable because its operation depends on the fact that there are specific d-c voltage relationships between the tube elements. Any variation of source voltage varies all these voltages in the same proportion, causing a minimum change in the voltage relationship since all voltages are supplied by voltage dividers across the same voltage source. The phantastron has the unique advantage over multivibrator circuits in that the pulse width, or delay, varies directly with one of the d-c applied voltages. This control by a d-c voltage makes remote control feasible at any distance through unshielded power cable since there is no signal present in the control circuit.

Study the basic phantastron circuit in figure 5-22. This circuit is never free running and is usually triggered by a negative pulse at the control grid (grid No. 1). Consider first the conditions before the trigger pulse arrives. Grids 2 and 4, which are tied together inside the tube, are connected to a voltage divider from plus 300 volts. The normal output of the divider is 86 volts. But with zero control grid voltage and 86 volts on grid 2, 4 ma. of current will flow to grid 2. This additional current in the voltage divider drops grid 2 to 68.7 volts. Grid 3 is connected to a voltage divider which sets its voltage at 27.3 volts. This grid does not draw current because it is negative with respect to the cathode. The current through the 10K cathode resistor is 4 ma. Since the cathode is 40 volts above ground, the grid 3 to cathode voltage is 40 -27.3 = 12.7 volts. When grid 3 is more than than 12 volts negative with respect to the cathode, it prevents electrons from passing it in their journey to the plate. Therefore, since the minus 12.7 volts is beyond plate-current cutoff for grid 3, no electrons will reach the plate. Thus, the plate voltage is plus 300 volts. The control grid

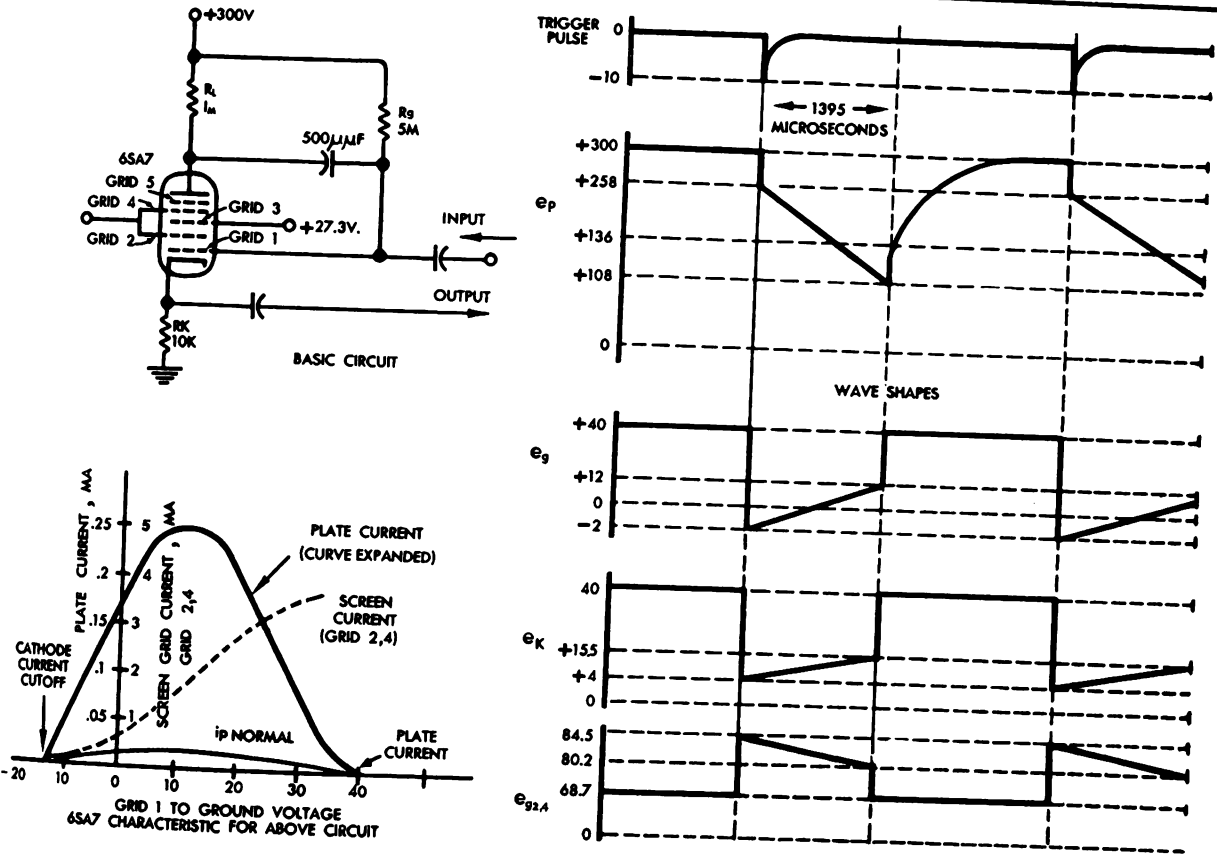

Figure 5-22.—Phantastron circuit and waveshapes.

connected to E_{bb} through a 5-megohm re- or. A very small grid current flows through cathode resistor, but the grid voltage may considered the same as the cathode voltage. ther words, the difference in potential be- en grid 1 and the cathode is zero. Grid 5, the oressor grid, is connected to the cathode and no part in the operation of the circuit other performing the normal function of a sup- sor grid.

The next factor to consider is the similarity een the phantastron and the start-stop uit. You can consider the 6SA7 phantastron as a tube within a tube. The cathode, grid d plate are equivalent to the first triode in tart-stop circuit. No plate current flows to plate and the "first tube" is cut off. The de, grid 1, and grid 2 form another triode is comparable to the second tube of the lop multivibrator. As mentioned previously, triode is conducting. Consequently, any e change, which will cause plate current to flow in the triode that is cut off, will start a regenerative switching action.

You can best understand the action of the phantastron when it is triggered by dividing it into three successive phases. The first phase is an extremely rapid change which ends at a first balance point. The second phase is a slow linear change which ends at a second balance point. The third phase is the recovery of the circuit to the pretrigger condition.

The trigger pulse must have the proper polarity and amplitude to bring grid 3 above cutoff. Since grid 3 is 0.7 volt beyond cutoff, 1 volt would do it. A negative pulse of 10 volts amplitude is shown. When this is applied to grid 1, the grid 1 voltage will drop to 30 volts. Cathode follower action will cause the cathode voltage to drop to 30 volts along with the grid. At this point, examine the relation between the cathode and grid 3. Their voltage difference is 27.3 minus 30, or minus 2.7 volts. Grid 3 is not negative enough to prevent electron flow to

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the plate and plate current will flow as soon as this grid-to-cathode voltage drops below 12 volts. Regenerative action starts with this plate-current flow. The plate current through R_L causes a drop of plate voltage. Grid 1 is capacitively coupled to the plate, so the grid becomes more negative. This drops the cathode voltage still more, which in turn further reduces the voltage difference between grid 3 and cathode. The current to the plate increases, the plate voltage drops, and the grid is driven farther in the negative direction.

Note that the plate current increase is NOT an overall increase in current with a negative-going grid. The negative-going grid decreases the total current slightly. But the resultant decrease in cathode voltage lowers the voltage between grid 3 and the cathode, which allows current to flow to the plate at the expense of the screen current. Grid 3 controls the DIVISION of current between the plate and screen grid. Grid 1 controls the total current. So grid 1 decreases the total current slightly, while grid 3 allows the plate current to increase and causes the screen current to decrease quite rapidly. The 6SA7 characteristic curve (fig. 5-22) shows the relation. In plotting these curves a d-c voltage was applied to grid 1 of the circuit in the illustration and varied from minus 20 volts to plus 40 volts. The dotted curve shows the resultant screen current while the other curve shows the plate current. Note that plate current (expanded in the fig.) increases by a small amount while screen current decreases a large amount as G_1 goes in a negative direction from plus 40 volts. The sum of the two currents is the cathode current. It is decreasing because the small plate current increase is more than overcome by the large grid 2 current decrease.

The regenerative effect just explained is similar to the cutting off of the first multivibrator tube by the second tube. The cutting off process, however, does not go that far in the phantastron, for if the current to the plate were stopped, the plate voltage would have to rise, and this action would be the opposite to the desired feedback. The increase of current to the plate ends at the first balance point. This balance occurs when the negative-going grid 1 voltage decreases the overall current so much that the plate current cannot continue to increase. Grid 3 is unable to divert enough electrons to the plate to maintain the increase of plate current, so the plate current stops increasing and becomes steady. This occurs when grid 1 has dropped to a minus 2 volts, and the plate has dropped 42 volts before the balance point is reached. Each of these voltages is shown in the curves, under the trigger pulse. The grid voltage has dropped to minus 2 volts. Since this is a 42-volt change, caused by the plate, the plate curve shows a 42-volt drop to 258 volts. The cathode voltage drops, due to the decrease in screen current, until with minus 2 volts on the grid, the current is 0.4 ma. The voltage at grids 2 and 4 has gone up because the screen current is decreased, reducing the drop across the voltage divider and raising its voltage to 84.5 volts.

Now consider the action resulting from the starting of the second phase. The capacitor from plate to grid at this time starts to discharge t the new lower plate voltage. At this time the gri voltage is minus 2 and the capacitor discharge from 300 to 260. In discharging, the grid end o the grid resistor becomes more positive. Thi increases the plate current, starting anothe drop in plate voltage. Grid 3 is not involve directly in this stage as it is straight triod action between the plate, grid 1, and the cathod that affects the circuit operation. The plate voltage drop has an effect opposite to that of t discharging capacitor and thereby is degenerative in action. The capacitor discharges, t grid goes POSITIVE, plate current increase plate voltage drops, tending to make the grid NEGATIVE. But the plate cannot drop enough exceed the positive charge at the grid because is the positive grid voltage that causes the plat voltage drop. So the plate-voltage char counteracts only PART of the effect of t capacitor discharge, slowing the discharge co siderably. This negative feedback keeps capacitor discharge in the most linear part the exponential curve. In fact, it can be sho mathematically that the time constant is leng ened by an amount equal to the amplificat factor of this triode. Looking at it in s another way, the exponential curvature at grid is counteracted by opposite curvature at plate due to the inverting properties of the tri tube.

The discharge continues at a linear rate shown by the plate-voltage curve illustrate figure 5-22. The increase in current raises cathode voltage to 15.5 volts, and the gr voltage is raised to plus 12 volts before second balance point is reached.

Remember that during all this time, screen grids (2 and 4) have been contin drawing current at an increasing rate. As the plate voltage continues to fall, there is a minimum point where the screen's current has risen sufficiently and the plate voltage has dropped to the point where the cathode potential is now high enough, in relation to the fixed potential on grid 3, to prevent any further increase in plate current. This occurs at about 108 volts on the plate. This point is also the peak of the plate-current characteristic (fig. 5-22). To the right of this peak, the plate current decreases and the screen current continues to increase. The screen grid's increasing current raises the cathode bias, thus the plate current stops increasing and levels off. This leveling off initiates the rapid switchover to recover the circuit to pretrigger condition.

When the plate current levels off, the voltage stops decreasing at the plate. With the counteracting effect of the plate drop removed, the capacitor discharge raises the grid 1 voltage at a very rapid rate. The positive-going grid 1 increases the current from the cathode, which raises the cathode voltage. This has the same effect as making grid 3 more negative; so grid 3 reduces the current to the plate. Actually, it is dividing the increasing current in favor of the screen grids. The screen current increases tremendously while the plate current is actually decreased. The plate voltage starts to go in the positive direction. This is coupled to the grid by the 500-$\mu\mu$f. capacitor to make it go in a positive direction. The cathode voltage is raised some more, which brings grid 3 closer to cutoff, reducing the plate current more and raising the late voltage. This regenerative action coninues until grid 3 is beyond cutoff—which stops late current completely. During this regeneraive action, the grid voltage has increased as ast as the plate voltage, so no change in voltage ccurs. But when the grid reaches plus 40 volts, he plate current reaches zero and the grid no onger affects the plate voltage. Thus, as the rid voltage jumps from 12 to 40, the plateoltage curve shows a 28-volt jump from 108 136 volts. When the grid voltage reaches a onstant value, the plate rises only as fast as e capacitor can recharge along a slow exnential curve up to plus 300 volts. The cathode ltage rises immediately with the grid voltage hile the screen grid voltage drops at recovery me because of the increased screen current.

Now consider the circuit from the viewpoint at it is ready for the next trigger pulse. The ration of operation, and consequently, the duration of the negative pulse on the cathode, is fixed in the circuit shown. This pulse width is determined essentially by the R-C in the grid 1 circuit, the plate voltage, and the gain of the triodes involved.

CHANGING PULSE WIDTH

The duration of the pulse is generally made variable by applying a d-c voltage to the plate from a potentiometer. The circuit is as shown in figure 5-23. The potentiometer can select any voltage from zero to plus 300 volts. A diode is inserted in series to disconnect the phantastron plate from the low-resistance potentiometer during the operation of the circuit. Before the trigger pulse, the plate voltage and voltage at the arm of the potentiometer are the same because the load resistor is so large and the current from the potentiometer so small that there is little voltage drop in the diode plate. When the circuit operates, the plate voltage drops immediately, the diode plate becomes less positive than its cathode, and diode current stops. The potentiometer-diode circuit has no further effect on the operation of the phantastron.

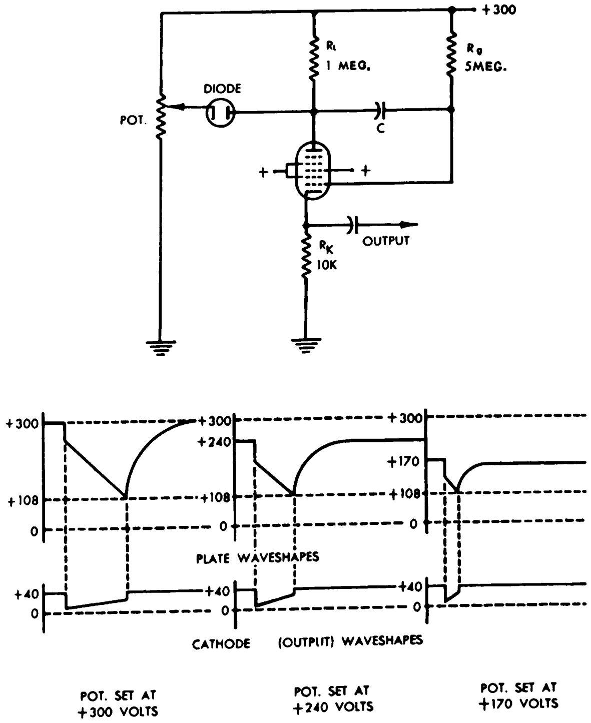

Figure 5-23.—Changing pulse width in phantastron circuit.

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To see how the potentiometer affects the pulse width, study the effect of varying the position of the potentiometer contact. With the plate voltage at plus 300 volts, the situation is as previously described. But when this plate voltage is reduced to plus 240 volts by means of the potentiometer, the pulse width is decreased. The plate voltage drops the same 42 volts at the time of the trigger pulse since the grid drops 42 volts to the first balance point. Then the slow linear voltage decrease occurs. The slope of this decrease is the SAME regardless of plate voltage. This terminates at the same 108 volts as the 300-volt waveshape. So the amount of linear decrease is less, which decreases the time required to reach 108 volts. If the potentiometer is set so the plate voltage is 170 volts before the pulse, the plate will again drop 42 volts, and follow the SAME slope to 108 volts. Again the amplitude of the slope is decreased so the slope time is decreased.

Since the initial drop, the slope, and the final value do not change, the decrease in pulse length is linear with the decrease in plate voltage. This relation holds over the range from the full plate voltage (300 volts in this case) to a minimum of 108 plus 42, or 150 volts. This is the minimum voltage point because the initial 42-volt drop would bring it down to 108 volts, or zero pulse width. Since the pulse width for the previous example used is 1,395 microseconds, the pulse width is variable from zero to 1,395 microseconds.

APPLICATION OF PHANTASTRON CIRCUIT

The phantastron circuit shown in figure 5-24 is taken from a typical radar set. It is similar to the previous circuit except that there the values and voltages are slightly different, the voltage dividers for grids 2, 3, and 4 are shown, and the disconnector diode is actually a triode with its grid tied to the plate. This last is done in the set to make use of the other half of a 6SN7 that is employed in another circuit. The potentiometer which sets the plate voltage has fixed resistors in each end to limit the pulse width to a certain maximum and minimum width which is adequate for the purpose for which it is designed.

The trigger pulse is applied to the cathode of the disconnector diode. The pulse momentarily changes the plate current in the diode, which causes the negative pulse to appear at the plate of the phantastron tube. The plate-to-grid coupling capacitor couples the pulse voltage to the grid where it starts the circuit through a

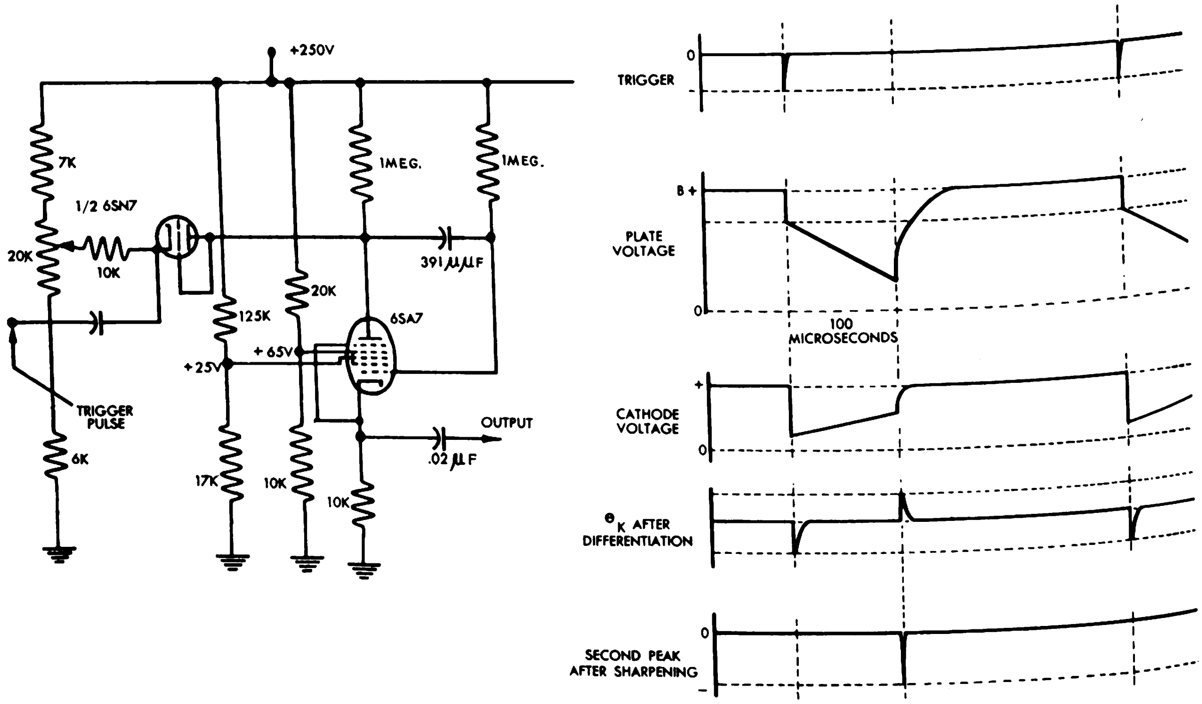

Figure 5-24.—Typical radar phantastron circuit.

cle of operation. The output is taken from the thode of the 6SA7, where a negative, ap- oximately square waveshape is produced. tually, the waveshape is not as ideally square shown in figure 5-22, because the trailing ge becomes somewhat exponential in following e capacitor charge.

In use, the square wave is usually dif- rentiated and the trailing edge pulse is put rough a pulse sharpening circuit to remove e effect of the exponential trailing edge. The sulting sharp pulse is delayed from the iginal trigger pulse by a few hundred micro- conds.

IANTASTRON WITH CATHODE FOLLOWER

The previous circuit is satisfactory for short lays, but when the delay becomes nearly as ng as the time between pulses, the long ponential recovery of the plate circuit over- ps the next pulse. With the circuit not yet fully covered, the second pulse may not trigger e circuit. Therefore the circuit is modified r long delay periods as shown in figure 5-25. ie change is the addition of a triode between e plate and grid of the phantastron tube. This ode is called a CATHODE FOLLOWER. Before e trigger pulse arrives, the grid of the cathode lower is at the the plate potential, it is draw- ; current, and the cathode is within a fraction a volt of the grid voltage. Therefore the 005-µf. coupling capacitor has the plate volt- e on one side and the grid voltage on the ier—which is not different from the circuit in ure 5-22. When the trigger pulse drops the te voltage, the grid voltage of the cathode lower, and consequently its cathode voltage, es down. The 0.005-µf. capacitor must dis- rge, and in doing so, makes grid 1 go in the ative direction. Thus by cathode follower ion, the grid drops right along with the plate though capacitive coupling existed between m.

When the end of the pulse arrives, and the te voltage rises back to static potential it s not have to charge the capacitor. The plate raise the cathode follower grid immediately lus 250 volts. Then the capacitor charges ugh a path from the 6SA7 cathode to grid 1, ugh the capacitor, from cathode to plate of cathode follower, to plus 250 volts. The grid he cathode follower is not involved, other than through interelectrode capacity, which is very small. Only a slight exponential curvature of the plate waveshape is shown in figure 5-25. This curve is due to stray wiring capacity in the circuit. The dotted curve shows the exponential rise which would interfere with the next pulse if no cathode follower were used. In all other respects, this long delay circuit is the same as the short delay circuit. In some equipments the square wave output is taken from the grids 2 and 4. This is a positive square wave, and when differentiated produces a negative pulse at the square wave's trailing edge.

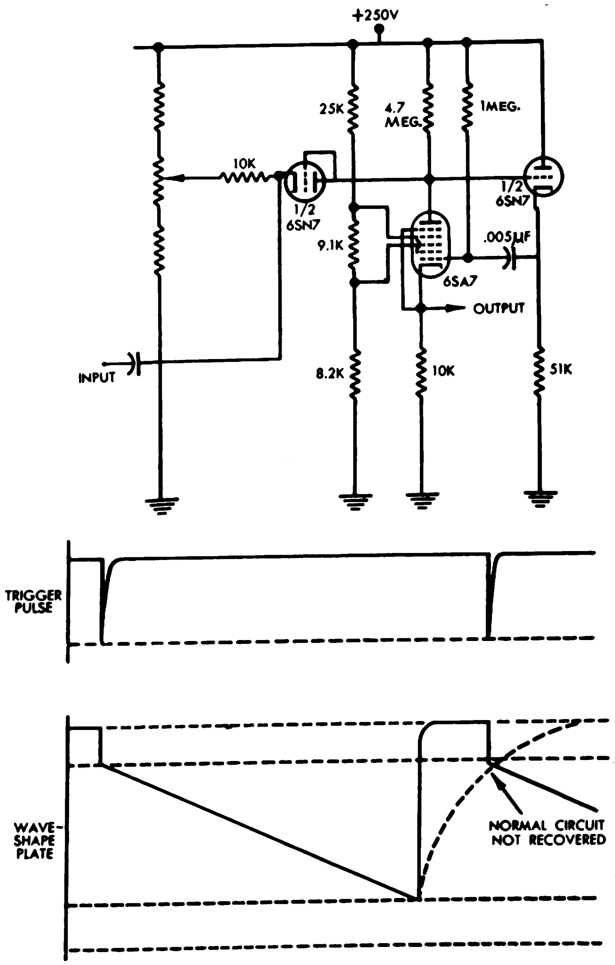

Figure 5-25.—Phantastron with cathode follower.

THE BLOCKING OSCILLATOR

The blocking oscillator is another type of relaxation oscillator. It can do many of the things that a multivibrator does. Thus it can be free

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running, synchronized at each cycle or at a submultiple frequency, or it can be driven in the manner of a one-shot multivibrator.

A blocking oscillator is any oscillator which cuts itself off after one or more cycles because of the accumulation of a negative charge on the grid capacitor. Thus, in an oscillator in which the grid swings positive with respect to the cathode, electrons are attracted to the grid and accumulate on the plate of the grid capacitor nearest the grid. Since these electrons cannot return to the cathode through the tube, they must return through the grid-to-cathode resistor. If this resistor is sufficiently large, electrons may accumulate on the capacitor faster than the resistor permits them to return to the cathode. In this case a negative charge is built up at the grid which may bias the tube beyond cutoff. After the tube is cut off, it provides no additional electrons to the grid capacitor. However, the capacitor continues to discharge through the resistor, and a point is reached eventually where the tube again conducts. Thus the process is repeated and the tube becomes an intermittent oscillator. The rate of the recurrence of operating conditions is determined by the R-C time constant of the grid circuit.

There are two general types of blocking oscillators—the SINGLE-SWING type in which the tube is cut off at the completion of one cycle, and the SELF-PULSING type, in which each cycle of oscillation causes the grid to become progressively more negative until the tube is biased out of operation. In radar the single-swing type oscillator usually operates within the audiofrequency range, while the self-pulsing type produces pulses of RF energy.

Single-Swing Blocking Oscillator

The single-swing oscillator circuit shown in figure 5-26 consists of a transformer-coupled oscillator, with a capacitor in series with the grid of the triode V_1. For the purpose of understanding its operation, assume that the grid capacitor C_g has been negatively charged by a preceding cycle. The tube, therefore, is biased well below cutoff. As the charge on the capacitor leaks off, the biasing voltage is reduced to the point where the tube begins to conduct. As plate current starts to flow, a magnetic field is set up around the plate winding P of the transformer. The dots at each winding indicate similar polarities. If, for example, a current flows through a winding so that the dot end is positive, the field set up in the core induces voltages in the other windings that make the dot end positive in these windings at the same time.

The field builds from zero to a maximum in direct proportion to the plate current, and therefore induces a voltage across the grid winding. This voltage is of such polarity that the grid end goes positive. This action is impressed upon the grid of the tube through the grid capacitor C_g with a polarity that drives the grid more and more positive as the field in the plate winding is building up. When the grid is driven positive with respect to its cathode, it draws current, and electrons accumulate on the plate of the grid capacitor nearest the grid. At the same time, current is flowing through R_g, making the grid positive. As the grid becomes more positive, it eventually takes enough electrons from the plate current to lower the rate of the plate current increase. This reduces the induced voltage from plate to grid windings, the grid stops swinging positive, and the plate current increase is slowed. This action is cumulative and ends with the plate current being settled at a constant value, and the magnetic field of plate winding P becoming stationary with respect to the secondary.

At this time there is no induced voltage in the grid winding and, because there is no charging potential applied, the capacitor begins to discharge. This discharge causes the potential on the grid to become less positive, thereby causing less plate current to flow in the plate winding. The field around the plate coil starts to collapse. This collapsing field, in turn, induces a voltage in the grid winding in the reverse direction, causing the grid to become more and more negative. This process continues until the grid is driven beyond cutoff, thus completing a cycle of operation. Oscillation does not start again immediately, however, because the flow of grid current when the grid was positive has built up enough charge on the grid capacitor to hold the tube cutoff until some of the charge leaks off through the grid resistor.

The time consumed by the rise and decay of plate current depends upon the inductance and resistance of the transformer. The time between pulses depends primarily upon the value of resistance since the grid capacitance is fixed because of pulse-width requirements.

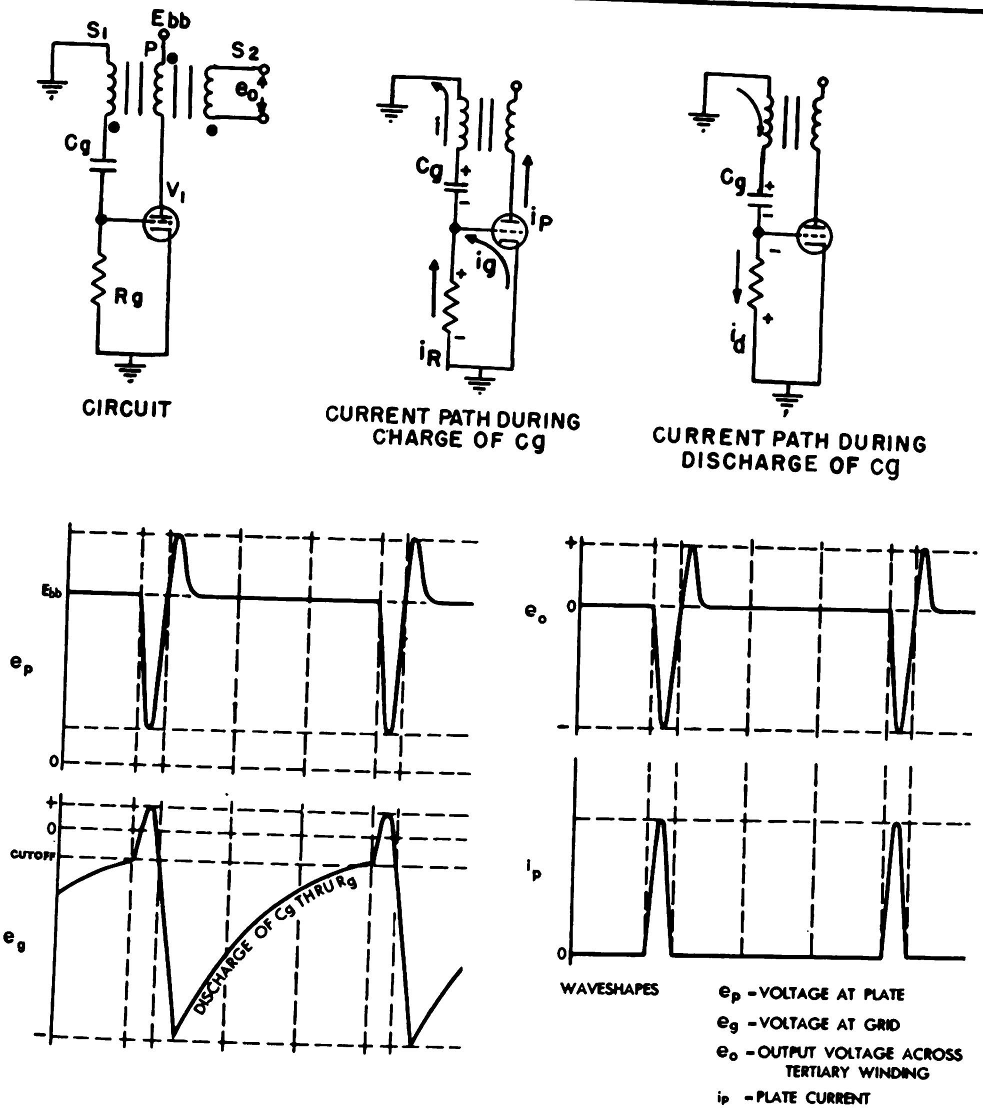

Figure 5-26.—Single-swing blocking oscillator.

te the current paths during charge and
rge. The capacitor charges very quickly
h the low-resistance of the conducting
athode circuit but discharges very slowly
h the large grid-leak resistance. The
d waveshapes show that the voltage and
t changes occur more slowly than in a
ibrator. This is due to the inductance
transformer. The inductance also is the
of the plate voltage rising above E_{bb} when
e is cut off. The current continues to flow
ame direction as it charges the distributed
y in the transformer windings, and causes
ge drop which adds to E_{bb}. The inductance
tributed capacity form a resonant circuit
ends to oscillate due to shock excitation.

If the Q of this L-C circuit is high, it may oscillate for several cycles. In the case illustrated (fig. 5-26), damping is at the critical value so that the oscillation occurs for about a half-cycle. Sometimes the plate winding of the transformer is swamped by a resistor to lower the Q, thereby damping oscillations very fast.

The output e_o from this circuit is taken from a third winding on the transformer. However, the output can also be taken from the plate, where a large negative pulse is produced, or from a small resistor in the cathode circuit, where a small but sharp positive pulse is available. The waveshape of the cathode pulse is the same as the plate current waveshape shown in figure 5-26.

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Synchronized Blocking Oscillator

The synchronized blocking oscillator in figure 5-27, is used as the timing oscillator in a small piece of auxiliary equipment. Normally, the set produces its own PRF independently when the oscillator is free running, as you can see in the waveshapes labeled "e_g, no sync." The natural frequency for its operation is about 300 c.p.s. However, synchronizing pulses can be introduced at the plate without making changes in its circuit that may vary the PRF. The synchronization pulses shown occur at 700 c.p.s. Their amplitude is such that one pulse makes the circuit operate, the next pulse does not bring the grid above cutoff, but the third pulse does make the tube conduct. Since the oscillator is synchronized on alternate pulses, its PRF becomes 700/2, or 350 c.p.s. If the main radar set has a PRF of 1,000 c.p.s. and the amplitude of the sync pulses is slightly less than that shown, the blocking oscillator can be synchronized on every third cycle, and it will operate at 333 1/3 c.p.s. By synchronizing this auxiliary set with the big set, indications received by the small set can be displayed on the main indicator, relieving the operator of observing two radar indicators at the same time.

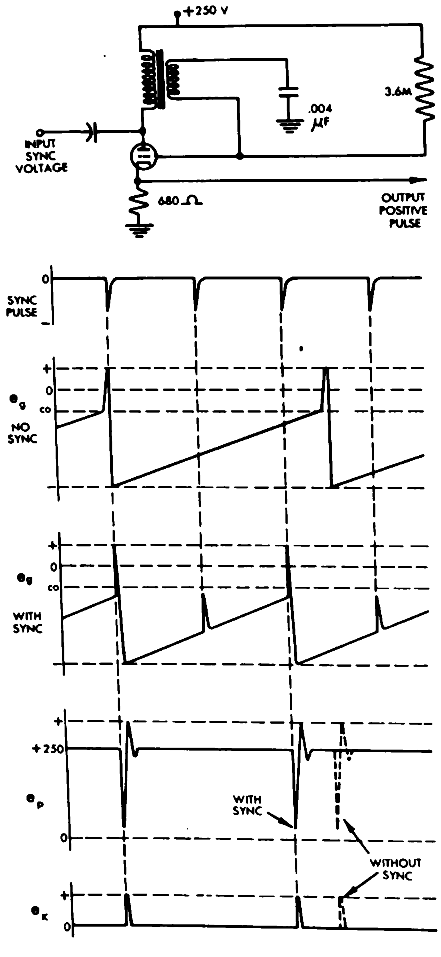

Figure 5-27.—Synchronized blocking oscillator.

The amplitude of the synchronizing pulse has a great effect on the frequency of this circuit. If the amplitude of the synchronization pulse shown is increased 50 percent, the first pulse that occurs after the circuit begins operation will bring the grid above cutoff and the circuit will be synchronized on every pulse. As stated before, a low amplitude could cause triggering on every third pulse since the first two will not have sufficient amplitude to make the tube conduct.

In each case, it is assumed that the natural period of the circuit is longer than the time between the pulses which cause the circuit to operate. If the period of the blocking oscillator is shorter, it will produce long and short cycles, because the circuit will be triggered on some pulses but will conduct on its own accord at times.

Maximum frequency stability is achieved in this circuit by connecting the grid-load resistor to the plate-voltage supply. This has the same effect as returning the grids to B plus in multivibrators. The useful output from this circuit is taken from a small (680-ohm) resistor in the cathode circuit. This resistor has a negligible effect on the operation of the circuit but develops a voltage pulse due to the plate current flowing through it.

The Driven Blocking Oscillator

Some electronic circuits require a blocking oscillator which operates only when triggered. Such a circuit might be called a BLOCKED OSCILLATOR since a permanent d-c voltage prevents the circuit from oscillating of its own accord. In the circuit of figure 5-28, only a positive voltage on the grid or a negative voltage on the cathode will cause the tube to conduct. If the voltage is a pulse, the circuit will go through a cycle of operation, cut itself off, and the d-c voltage will keep it cut off. Cutoff is maintained by a voltage divider from the plate-supply voltage. With the values shown, the cathode voltage will be plus 50 volts with

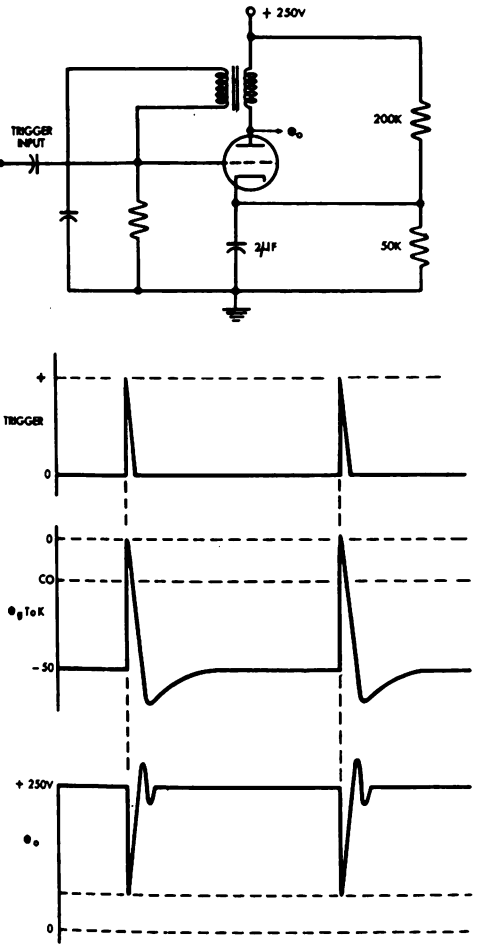

Figure 5-28.—Blocked oscillator.

'ct to ground. The grid is grounded, and refore 50 volts negative with respect to the de. The grid waveshape shows voltages respect to the cathode since these are the 'tant voltages in understanding the circuit tion. Cutoff for most tubes used in this ircuit occurs at about minus 18 volts, so igger pulse must be more than 50 minus 32 volts in amplitude to start a cycle of ion. In the grid waveshape the normal rge of the grid capacitor reduces the grid after a cycle of operation, but the dis- is to a minus 50 volts, so the circuit iot again conduct without another trigger

positive trigger pulse must be applied grid only. It is not practical to apply a pulse to the cathode because the filter or is usually found there. But a nega- lse may be applied to the plate, where the transformer will invert the pulse to a positive one on the grid. The output may be taken from the plate, where a large negative pulse is available, or from a third transformer winding where a pulse similar to the plate pulse can be obtained with either polarity.

USE AS A PULSE SHARPENING CIRCUIT

The driven or blocked oscillator is useful as a pulse sharpening circuit. One radar uses the circuit in figure 5-29 to improve the pulse shape from the phantastron. The phantastron produces the negative square wave pulse labeled input waveshape. This square wave is amplified and becomes the input to the differentiating transformer shown in the circuit. The waveshape at the secondary of the transformer is a

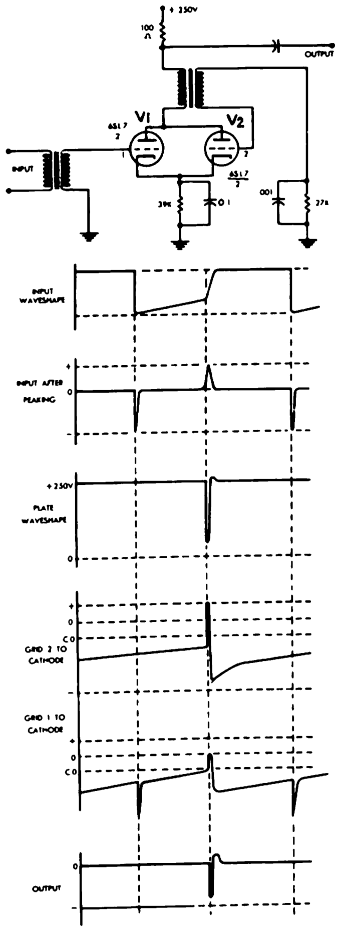

Figure 5-29.—Blocked oscillator as a pulse sharpening circuit.

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peaked wave, as shown in the second waveshape, but because of the inherent imperfections in the trailing edge of the phantastron pulse, the peaked wave due to the trailing edge is not a sharp one. For precise triggering of the circuits following the phantastron, a sharper pulse is required. Therefore the peaked wave is applied to the blocked oscillator.

In place of the voltage divider from plus 250 volts used in the earlier circuits, a long time constant in the cathode circuit provides the cutoff voltage. After several cycles of operation, the grid current due to positive grid voltages charges the cathode capacitor. It will discharge slowly between cycles and be recharged with each cycle. The R-C combination in the grid circuit (resistance and distributed capacity) is rather short and cannot hold the grid below cutoff for the several hundred microseconds required between pulses.

The negative pulse at the leading edge of the square pulse will not affect the already cutoff tube. The positive pulse at the trailing edge will cause the left tube to conduct. The current through the transformer and associated magnetic field will induce a positive voltage at the grid of tube V_2. This starts a regenerative action in the blocking oscillator associated with tube V_2 and it goes through a normal cycle of operation. Meanwhile the pulse ends at the grid of tube V_1, and with no other voltage on the grid, the tube is cut off again.

Tube V_1 is an amplifier and isolation circuit which causes the blocking oscillator to start very soon after the trigger pulse arrives, then disconnects the triggering circuit from the blocking oscillator so it can go through its normal cycle unaffected by the triggering circuit.

The output is taken from a small resistor above the transformer in the plate lead. A sharp negative pulse of low amplitude is produced across the resistor.

COUNTING CIRCUITS

A counting circuit, also known as a frequency divider, is one which receives uniform pulses, representing units to be counted, and produces a voltage proportional to their frequency. By slight modifications the counting circuit is used in conjunction with a blocking oscillator to produce a trigger pulse which is a submultiple of the frequency of the pulses applied.

The pulses applied to the counting circuit must have the same amplitude and time duration if accurate frequency division is to be made. Counting circuits, therefore, are ordinarily preceded by shaping and limiting circuits to insure this uniformity of amplitude and width. Under these circumstances the pulse-repetition frequency constitutes the only variable, and frequency variations may be measured.

The Positive Counter

Positive pulses, which may vary only in their recurrence frequency, are applied to the input of the positive counter as shown in figure 5-30.

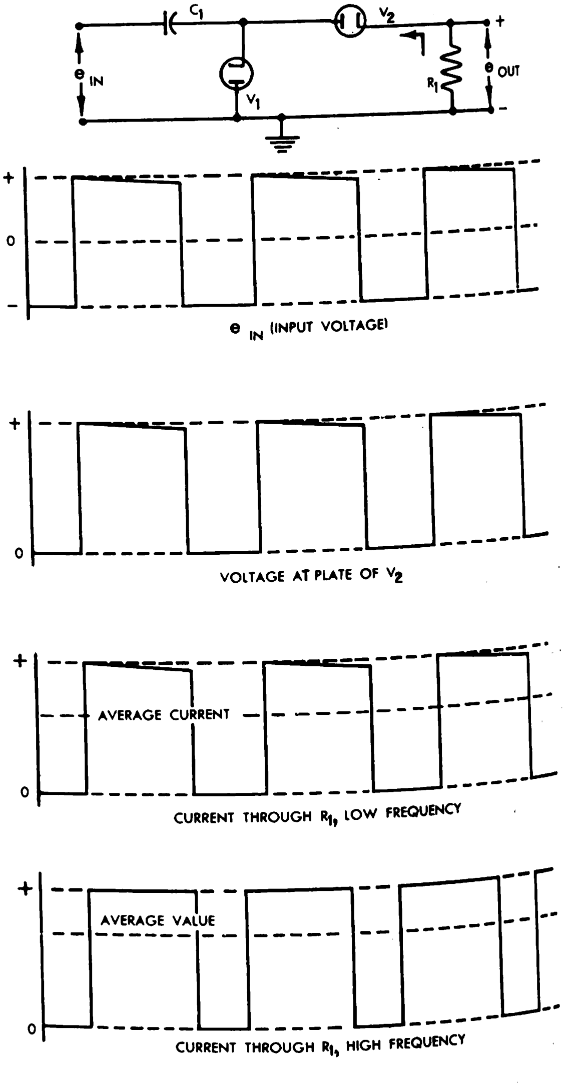

Figure 5-30.—The positive counter.

e charge on the coupling capacitor C_1 cannot inge instantaneously as the positive leading ge is applied, so the plate of V_2 becomes sitive and the diode conducts. A charging cur- t flows through R_1 during the pulse time and mall charge is developed on C_1. At the end he pulse the drop in voltage places the diode e of the capacitor at a negative potential equal he charge accumulated on C_1.

Tube V_2 cannot conduct, as its plate is nega- with respect to its cathode. However, V_1 ducts, discharging the small charge from the acitor, which would otherwise build up during h succeeding positive pulse, eventually ren- ing the circuit insensitive to the applied es.

CUIT CONTROLLED BY POSITIVE NTER

ince a certain amount of current flows igh R_1 each time a pulse is applied, an age current flows which increases as the e recurrence frequency increases and de- ses as this frequency decreases. The IR developed across R_1 can be used to control cceeding stage as is illustrated in the cir- controlled by a positive counter (fig. 5-31). filter in the grid circuit of V_3 aids in ob- ng smooth operation by removing too rapid es in voltage developed across R_1. The ge developed across R_1 is the average ge of the applied signal as shown in figure This voltage will vary directly as the ency of the applied signal varies; that e average voltage will increase as fre- y increases, and decrease as frequency ases. A milliammeter is placed in series the plate circuit so that changes in the ge plate current are indicated as a meas- variations in the recurrence frequency input pulses.

was stated earlier that the applied wave- may vary only in frequency. Glance at 5-30. If the pulse width or amplitude of lied signal varies, then the average cur- nd therefore the average voltage, across l vary. This circuit is intended to indicate s in frequency by measuring the average across R_1, so frequency is the only on that can be permitted. The applied are first sent through limiting circuits re exact amplitude, and shaping circuits e exact pulse width.

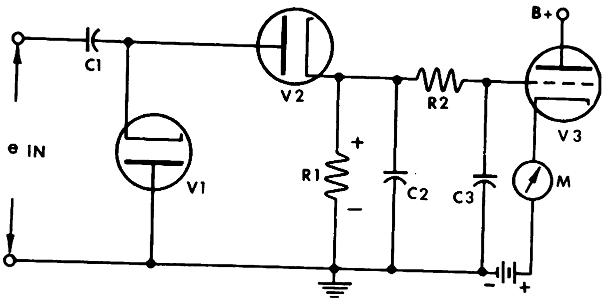

Figure 5-31.—Circuit controlled by positive counter.

This counting circuit is frequently found in radio altimeters.

The Negative Counter

By reversing the connections to the diodes V_1 and V_2 in the positive counting circuit the device can be made to respond to negative pulses, and thus it becomes a negative counter circuit. This circuit is shown in figure 5-32. The diode conducts during the time the negative pulse is applied and a current flows through R_1 as indicated by the arrow. At the end of the negative pulse V_1 conducts sufficiently to remove the small charge which developed on C_1 during the pulse time. The current through R_1 increases with an increase in the pulse frequency as before. However, if the voltage developed across R_1 is applied to the same control tube shown previously, the increase in current causes the grid of V_3 to become more negative. This decreases the plate current through V_3 and the meter. Thus an increase in the frequency of the negative pulse causes a drop in the average plate current measured by the meter. This effect is the opposite to that in the positive counter.

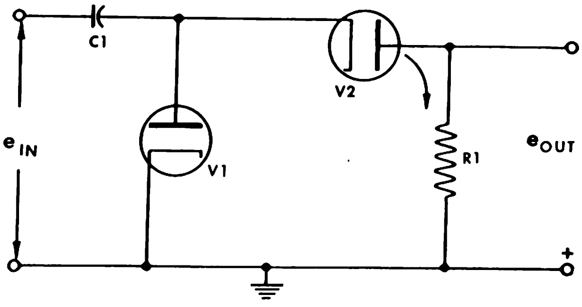

Figure 5-32.—Negative counting circuit.

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The Step-by-Step Counter

The step-by-step counting circuit is similar to those already discussed except that a capacitor which is large compared to C_1 replaces the resistor R_1 used in the positive counting circuit. The charge on this capacitor, C_2 (fig. 5-33) increases slightly during the time of each positive pulse and produces a step voltage across the output. These steps decrease in size exponentially as the voltage across C_2 approaches the final value, the rate being dependent upon the output impedance of the driving circuit. As long as there is no path through which C_2 can discharge, the voltage across it continues to increase with each successive pulse until it is equal to the amplitude of the applied signals. At this point the cathode of V_2 is held at a positive voltage equal to that on the plate during the pulse time and the tube fails to conduct. Note that the charge on C_2 will eventually approach 100 volts, the peak-to-peak value of the applied signal. This is caused by the charge on C_1 being in series aiding with the input voltage during the negative half cycle of input.

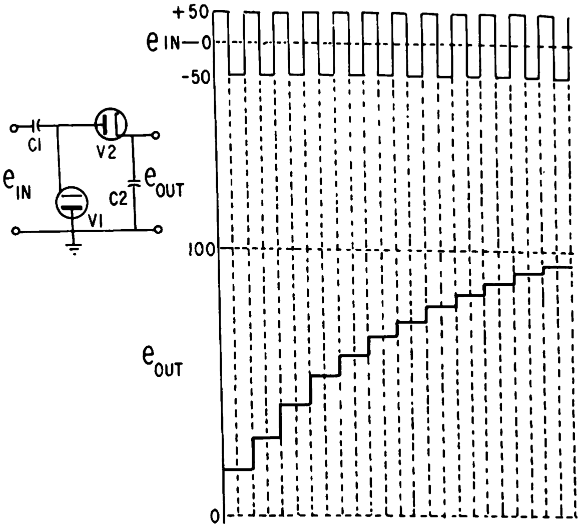

Figure 5-33.—Step-by-step counting.

CIRCUIT ACTION AND WAVESHAPE ANALYSIS

Use is made of the step charging circuit to trigger a blocked oscillator after a certain number of steps. A simple circuit of this type is shown in figure 5-34. The step-by-step counter determines the voltage on the blocked oscillator grid. The cathode has a high fixed bias on it, and a certain number of steps are required to raise the grid near enough the bias level to make the tube conduct. When the tube conducts, the blocking oscillator circuit goes through a normal cycle. The usual grid current during this cycle discharges the capacitor C_2. At the end of the cycle, C_2 charges in steps again, starting from zero.

This circuit is not difficult to analyze quantitatively. The following is the calculation of the exact frequency division ratio in the circuit. In the step-charging circuit, the time constant of the charging circuit is short since only the diode plate resistance is in series with the capacitors. Therefore, the capacitance is fully charged during each cycle of input waveshape. But the capacitors are in series, so the full charging voltage will be divided between the two. The voltage distribution in capacitors is in inverse ratio to the values of the respective series-connected capacitors and is mathematically expressed,

$$\frac{C1}{C2} = \frac{E2}{E1}$$

In this equation,

$C1$ = Capacitance of first series capacitor.
$C2$ = Capacitance of second series capacitor.
E_2 = Charge on C_2 if applied voltage is E_1 plus E_2.
E_1 = Charge on C_1 if applied voltage is E_1 plus E_2.

The voltage in question is E_2. Let the applied voltage be E_a. The equation for the E_2 voltage becomes:

$$E_2 = E_a \frac{C1}{C_1 + C_2}$$

Using the values indicated in figure 5-34,

$$E_2 = 100 \times \frac{0.01}{0.01 + 0.09}$$

$$E_2 = 100 \times \frac{0.01}{0.1}$$

$$E_2 = 10 \text{ volts}$$

The charge on capacitor C_2 with 100 volts applied will be 10 volts, while the capacitor C_1 will charge to 90 volts. It follows that the first

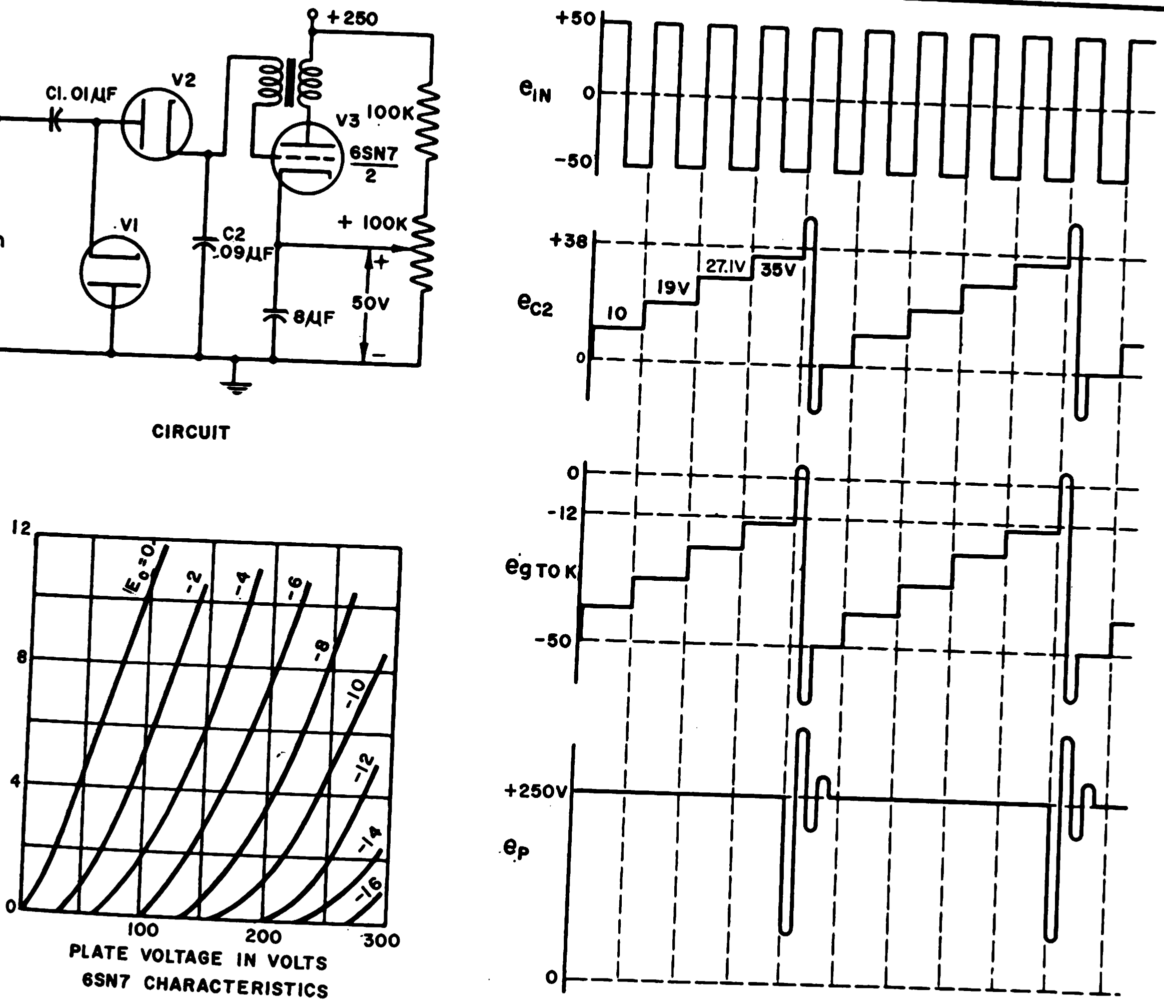

Figure 5-34.—Triggering blocked oscillator with step-charging circuit.

10 volts, which is 10 percent of the ap-
tage. The first step is 10 volts because
waveshape is 100 volts peak-to-peak
irst capacitor and diode V_1 form a DCR
urrent restorer) circuit which allows
tive voltages on the plate of the second
. Therefore the applied voltage is plus
during the pulse and C_2 is charged to
t of the total.

rst input pulse ends, C_1 is discharged,
olds its 10-volt charge. The second
urs. The 10-volt charge on C_2 will
e 100 volts of the second pulse, and the
ed voltage, to which the capacitors can
then 90 volts. E_a will be 90 volts,
the previous equation, C_2 will again
d by 10 percent or 9 volts. This is in
o the initial 10 volts, so at the end of
the second pulse, the C_2 voltage is 10 plus 9 or 19 volts. The third pulse will be 100 volts again, but 19 volts will oppose it. Therefore the E_a will be 100 minus 19 or 81 volts and C_2 will charge an additional 8.1 volts. The new E_2 becomes 19 plus 8.1 or 27.1 volts. Successive input pulses will raise C_2 by 10 percent of the remaining voltage toward plus 100 until the blocked oscillator is actuated.

In the oscillator, the bias is set at plus 50 volts. The plate-supply voltage is 250 volts, so the plate-to-cathode voltage is 200 volts. Using the plate-to-cathode voltage, you can determine the grid voltage for cutoff. From the curves in figure 5-34, this value is near minus 12 volts, as indicated on the characteristic curves. With the cathode at plus 50 volts, the grid must be within less than 12 volts of this

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value, that is, above 50 minus 12, or 38 volts to allow conduction. So the steps continue until 38 volts is exceeded. Since the fourth step is 35 volts and the fifth step 41 volts, the 38-volt level is crossed between the fourth and fifth steps.

The blocked oscillator goes through one cycle of operation at the end of which the "bucket capacitor" is discharged. Since every fifth input pulse results in an output pulse, this circuit is a 5-to-1 frequency divider.

To cause the circuit to divide by three, four, or some other value, the bias is set at some new value. For example, a bias of 36 volts would cause the crossover with cutoff voltage to occur at the end of the third pulse, making the circuit a 3-to-1 count divider. The sizes of the steps can be varied by changing the ratio of the two capacitors. For example, if C_2 is changed to 0.04 μf., it will take 20 percent of the charge, and the 38-volt level will be crossed at the end of the third pulse, causing division at a 3-to-1 ratio. In practice, this frequency division can be carried to the extent that with six successive frequency dividers, a 100,000 c.p.s. sine wave can be reduced to 50 c.p.s. The final circuit will be triggered on each two-thousandth cycle of the original voltage.

AUTOMATIC FREQUENCY CONTROL (AFC)

The term AFC refers to an automatic system incorporated in a radio or radar receiver circuit for the purpose of maintaining the correct local-oscillator frequency. Almost all Navy radar equipments make use of an AFC system.

Transmitters that produce frequencies in the UHF and microwave ranges have poor frequency stability. This is caused by factors which have negligible effect at lower frequencies. A partial listing of the cause of frequency instability at UHF and microwave ranges in transmitter oscillators and local oscillators is as follows:

1. Small physical size. Since the frequency determining components are small in physical size any condition that changes their shape or size will cause a shift in frequency. Factors that cause these components to change their characteristics are vibrations, variations in temperature, and variations in atmospheric pressure.
2. Frequency pulling. This is the result of load variations which are caused by variations in the length of transmission lines, or reflections from nearby objects such as sea return, aircraft surfaces, or the radome.
3. Voltage variations. These are caused either by variations in the source of power or poor regulation in the equipment's power supply.

Because of the previously presented inherent conditions it is important that the tuning of a microwave receiver to the proper frequency be automatic.

Some of the properties of microwave oscillators which may be used for frequency control are:

(1) Those of a magnetron—mechanical, thermal, pulling, and varying flux field density.

(2) Those of a klystron—mechanical, thermal, pulling, and electrical.

The system most often used and the one that will be described for the purpose of enabling you to gain a fuller understanding of AFC is the system which controls the repeller voltage of the local oscillator. This is the more practical method because a change in frequency is nearly linear with a change in voltage; also, changes up to 60 megacycles are practical. The operation of this type of oscillator, known as the klystron, will be explained in detail in chapter 7.

CLASSIFICATION OF AFC SYSTEMS

AFC systems are classified in accordance with their method of operation. The method of operation may be divided into two major classifications, the ABSOLUTE and the DIFFERENCE FREQUENCY systems.

In the absolute frequency system the frequency of oscillation is determined by a precision frequency standard such as a high-Q cavity. This system is generally used to keep the receiver tuned to the beacon (RACON) frequency. In the difference frequency system the local oscillator is maintained on a frequency which is greater or less than the magnetron frequency by an amount equal to the intermediate frequency. This keeps the receiver tuned to the magnetron during search operation.

Either of these systems may be a nonhunting or hunting type construction. The hunting system is constructed to cause the oscillator to sweep a wide frequency range. This enables the oscillator to find the correct operating frequency and once this has been accomplished the oscillator will automatically remain on the correct frequency. This system has the advantage that in the event of a sudden shift in magnetron or

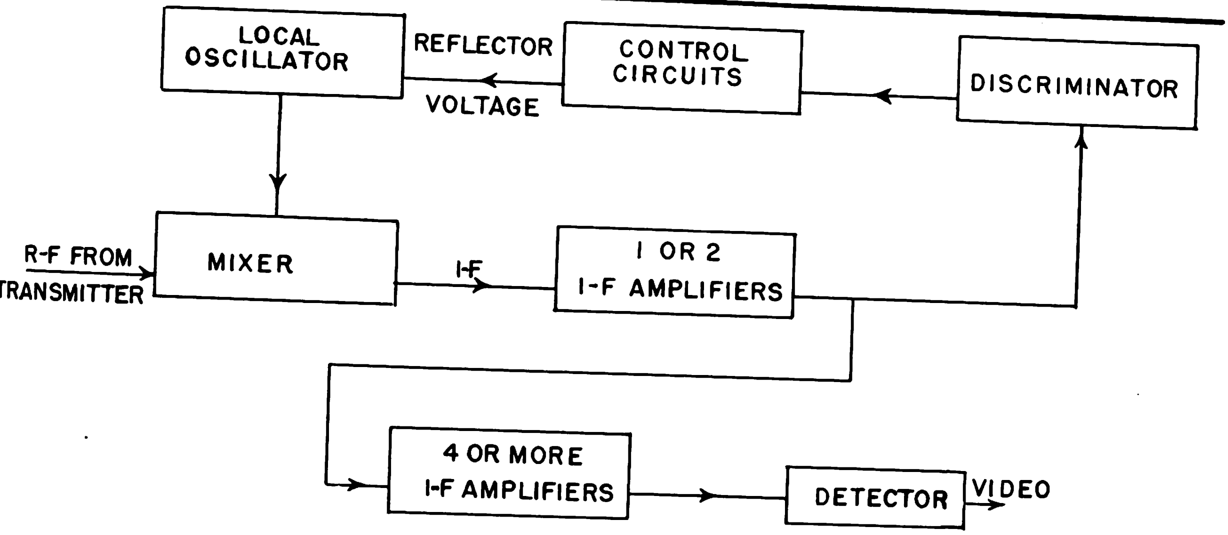

Figure 5-35.—Block diagram of AFC circuit in a radar receiver, single-mixer system.

l-oscillator frequency the correct operating uency will be found automatically. In the unting system the oscillator is manually l to the correct frequency and then main- d electronically to this frequency.

CK DIAGRAM OF AFC SYSTEM

the single-mixer system (fig. 5-35), a on of the transmitter pulse leaks through R box and beats with the local-oscillator l in the mixer. The difference frequency, e IF signal, appears at the output of the . This IF signal is then amplified by one o stages of IF amplification. At this the signal follows two paths—it is further ied and fed into the detector, and it is ed into the AFC discriminator. The output of the discriminator is fed to either a d-c amplifier or some special control circuits which regulate the klystron reflector voltage. The regulation of this voltage changes the frequency of the klystron and enables it to oscillate at the correct frequency.

Most modern radar systems use a double-mixer AFC system, as shown in figure 5-36. The separate signal and the AFC mixer are both connected to the same local oscillator. This arrangement is shown in figure 5-36. The AFC mixer is coupled to the transmission line through an attenuator which reduces the transmitted pulse and received signals by the same ratio. With this arrangement, strong signals from nearby radar, jammers, or sea return cannot affect the operation of the AFC loop.The double-mixer system is similar to the single-mixer

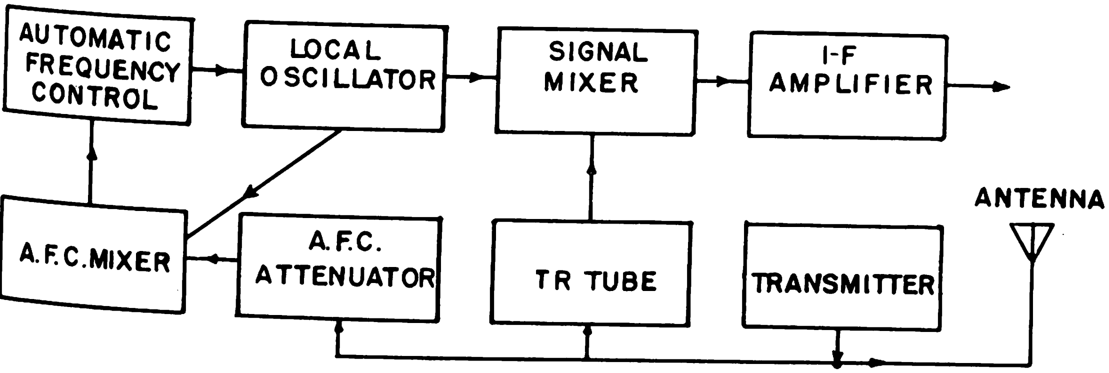

Figure 5-36.—Block diagram of a double mixer AFC system.

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system with the exception that it contains an AFC attenuator and separate IF stages.

THE DISCRIMINATOR CIRCUIT

The amplified output of the AFC mixer is fed into the AFC discriminator. The output voltage of a frequency discriminator varies in amplitude and polarity with changes in the applied frequency. If the applied frequency is at the resonant or center frequency of the discriminator the output will be zero. If the applied frequency is above or below the correct value, the output of the discriminator will be either positive or negative, depending upon the direction of deviation. The operation of this type of discriminator is explained in detail in *Basic Electronics*, NavPers 10087.

THE THYRATRON AFC CONTROL CIRCUIT

This circuit is an automatic hunting and lock-in type. A simplified diagram is shown in figure 5-37. Since the discriminator time constant is short, a pulsed output is produced. These pulses are amplified and inverted by the video pulse amplifier.

In the circuit shown in figure 5-37, V_2 functions as a sawtooth sweep generator. The output of this generator is applied to the repeller of the klystron. This causes a wide frequency band to be swept by the klystron and provides a "hunting action," which is a requirement of the AFC system. Lock-in action is obtained by V_1 once the proper IF signal is produced. During the time that V_1 maintains lock-in, V_2 will remain cut off because the action of V_1 prevents the plate potential of V_2 from rising to the point of tube ionization.

In the explanation of this circuit it is assumed that the radar transmitter is turned off. There will be minus 30 volts bias applied to V_1 because of the 30-volt drop across R_1 and R_2. This IR drop is a function of the divider network R_1, R_2, and R_3. V_1 will remain cut off because there will be no signal input to the grid until the transmitter is turned on. Since C_5 cannot be charged instantaneously, the moment that power is applied V_2 will have zero volts bias and a plate-to-cathode potential of plus 225 volts. As a result of these potentials, the gas in V_2 will ionize and the tube will conduct. During the time that V_2 conducts, C_4 will charge very fast towards a minus 225 volts through the low internal resistance of V_2, and the plate-to-cathode voltage of V_2 will decrease. (The de-ionization potential of a gas tube is a function of the type of gas, the pressure, and the fixed geometrical characteristics of the tube.)

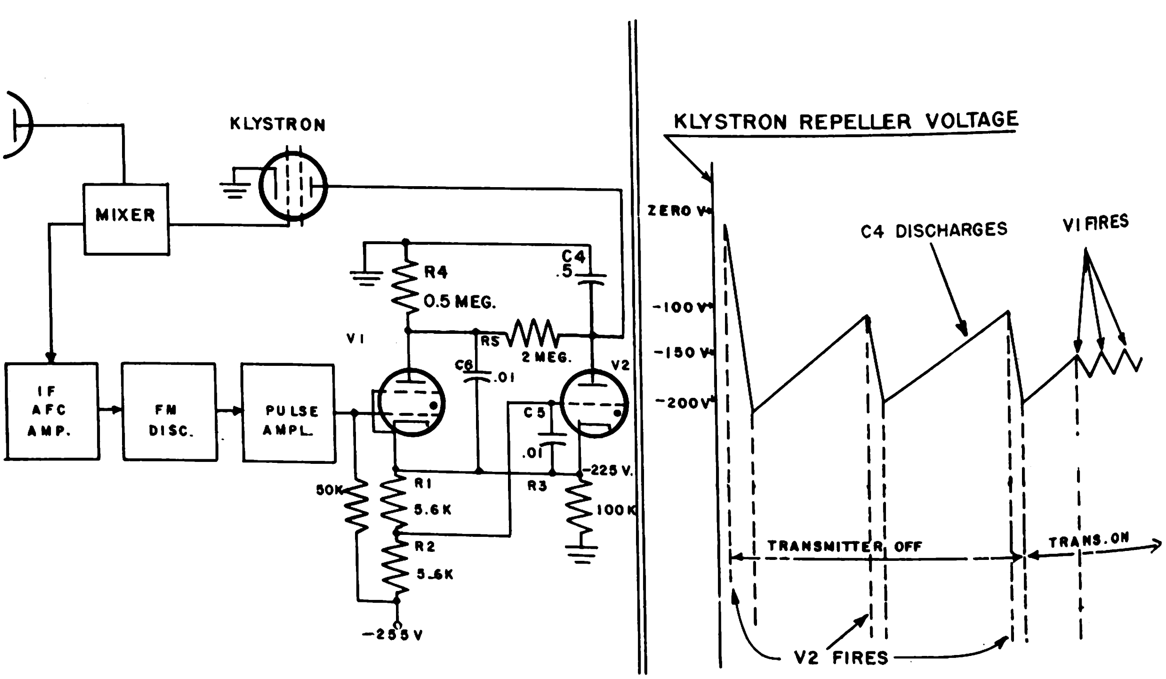

Figure 5-37.—The thyratron AFC control circuit.

The tube used in this circuit, V_2, will de- onize at 25 volts. Thus, when the charge on $_4$ has reached 200 volts, V_2 will de-ionize. hen this occurs, C_4 discharges slowly through 4 and R_5 to ground and the plate of V_2 be- omes less negative. The discharge continues ntil the charge on C_4 is about 100 volts. At is point, the plate-to-cathode potential is fficient to again ionize the tube. (The ioni- tion potential of a gas tube is a function of s grid bias.) The sawtooth output of V_2 is plied to the klystron repeller and since this tput voltage varies between a minus 100 and minus 200 volts the amplitude of the sawtooth aveform is 100 volts. The recurrence fre- ency of this sawtooth is approximately one cle per second.

To aid in understanding how the AFC loop completed, assume that the klystron will cillate at the proper frequency when its re- ller voltage is between minus 170 and minus) volts. As a result of V_2's sawtooth output, oscillator will be electrically tuned through proper frequency during each sawtooth riod. When the transmitter is turned on, as- ne that the proper intermediate frequency will obtained with a repeller voltage of minus 155. en the repeller is more negative than minus volts the input to the grid of V_1 will be ative. Thus, V_1 will remain cut off. The charge of C_4 causes the repeller voltage to ome less negative.

As this voltage becomes less negative than us 155 volts, the input to the grid of V_1 will positive pulses. At some frequency the es will be of sufficient amplitude to ionize thus providing a new charging path for C_4. path extends from the minus 225 volts on hyratron cathodes through V_1 and R_5 to C_4. C_4 again charges, the repeller voltage will n become more negative; when this voltage es through the minus 155-volt point, the to V_1 will again become negative pulses. , V_1 will de-ionize as soon as C_6 discharges gh it. The de-ionization occurs when C_6 has harged to the de-ionization potential of V_1 h is about 25 volts. As a result of C_6 taining V_1 in conduction for a period of it effectively increases the width of the s applied to the grid of V_1. After V_1 has nized, C_4 will again discharge through R_4 R_5 to ground. This entire cycle will be ted at a rate of about 200 c.p.s.

ne amplitude variation of the repeller volt- s so slight that the variation in klystron frequency is only a small fraction of the receiver's IF bandwidth. Because of this action the receiver will remain tuned, or locked-in, to the transmitter frequency. When the circuit is locked-in, V_1 will be conducting periodically and V_2 will remain cut off. Thus V_2 is effectively disconnected from the circuit. The only purpose of V_2 is to provide a slow-continuous sweep to hunt for the proper operating point and to reestablish circuit operation. This action will occur whenever AFC operation is interrupted.

A BEACON AFC CIRCUIT

When a radar is on beacon operation the receiver must be tuned to some specific frequency whether or not signals are being received. This requires an ABSOLUTE frequency hunting AFC system for reliable operation. The diagram shown in figure 5-38 is typical of such systems. The output of the klystron is fed to two places—(1) the receiver crystal, where it mixes with the beacon signal and produces the proper IF frequency for the receiver, and (2) to a precision tuned cavity for AFC operation. The filtered output of this detector is a sine-wave voltage (A or B) which is amplified by three audio amplifier stages and applied to the control grid of a phase discriminator (sometimes referred to as a coincidence tube).

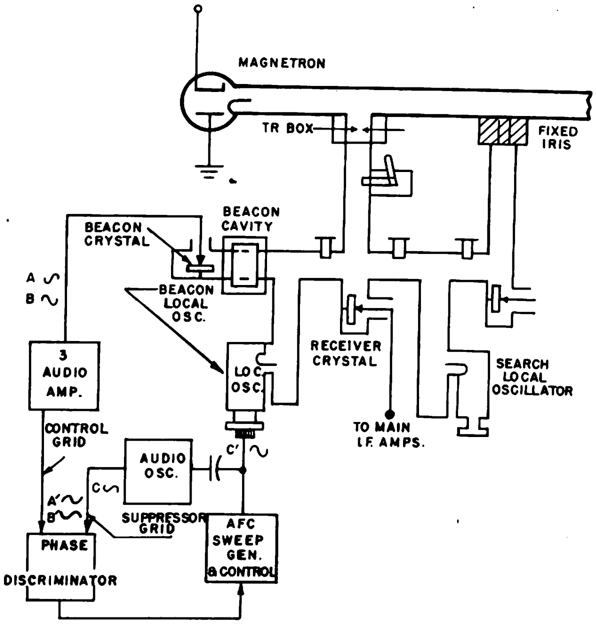

Figure 5-38.—Block diagram beacon AFC loop, using slope discriminator.

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The AFC sweep generator and control circuits used in beacon operation are similar in operation to those used in figure 5-37. Some radar systems use the same AFC sweep generator and control circúits for both radar and beacon. In the following discussion you will note that the phase discriminator, beacon cavity, and other associated circuits replace the frequency discriminator in figure 5-37, during beacon operation. This provides the proper input to the AFC control tube for locked-in operation when no receiver signal is present.

In addition to the sweep control circuit, such as used in a thyratron AFC system, the output of a one-thousand cycle audio oscillator (C) is capacitively coupled to the repeller of the klystron. (The amplitude of this audio signal is small, about 0.5 volt.) Thus, the klystron is not only swept over a wide range by the sweep generator, but it is frequency modulated at an audio rate. The purpose of frequency modulating the klystron signal at an audio rate is to furnish a sine-wave output from the crystal detector that will denote whether the klystron frequency is above the cavity frequency or below it. As the klystron frequency is swept through the resonant frequency of the cavity the audio sine wave reverses in polarity. The crystal output will have the polarity of either A or B in figure 5-38. These outputs are the result of slope detection. Slope detection is accomplished in the following manner.

In figure 5-39 note that the beacon cavity is fix-tuned to 9,250 mc. Note also that the klystron can be made to vary in frequency above and below the cavity's center frequency. Consider that the klystron frequency is operating below the cavity center frequency at point X, a point determined by the negative voltage on the klystron's repeller plate. Now consider the effect on klystron frequency when the audio signal modulates the repeller voltage—as the audio

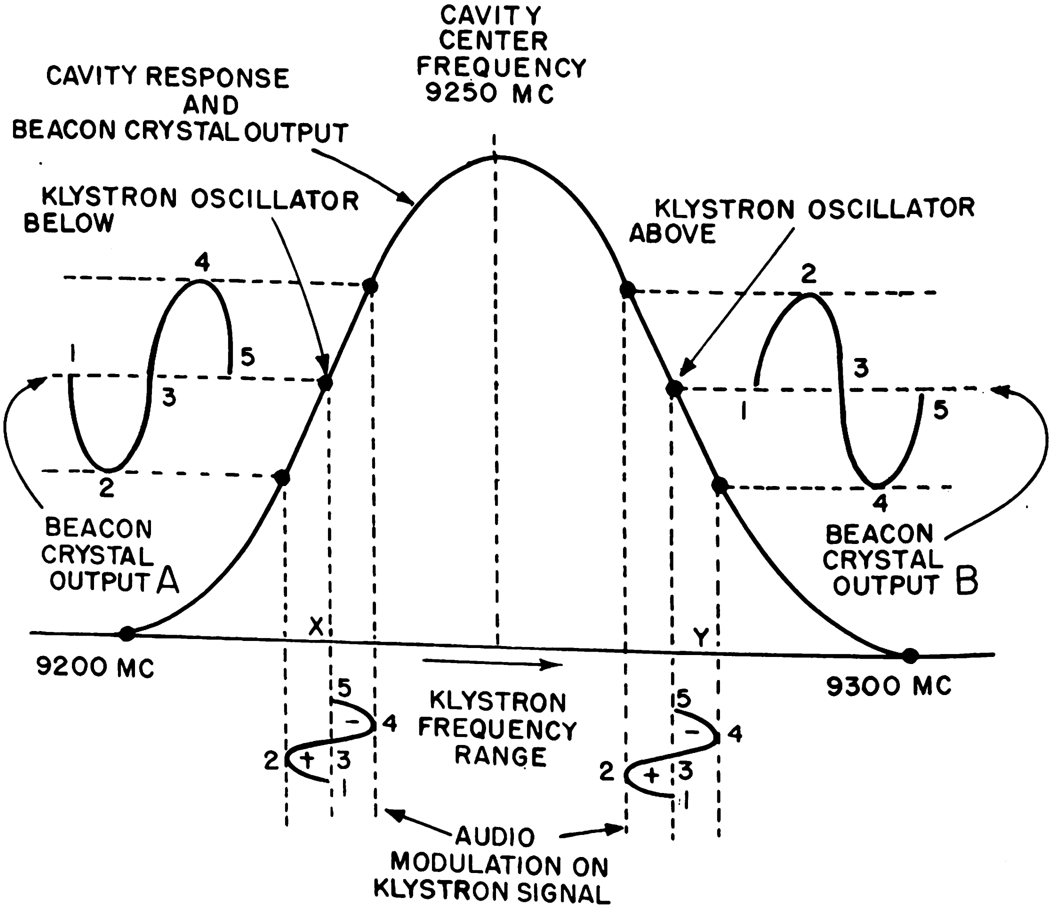
CAVITY CENTER FREQUENCY 9250 MC
CAVITY RESPONSE AND BEACON CRYSTAL OUTPUT
KLYSTRON OSCILLATOR BELOW
KLYSTRON OSCILLATOR ABOVE
4
1
5
3
2
2
3
1
5
4
BEACON CRYSTAL OUTPUT A
BEACON CRYSTAL OUTPUT B
X
Y
9200 MC
9300 MC
5
−
4
2
+
3
1
KLYSTRON FREQUENCY RANGE
5
−
4
2
+
3
1
AUDIO MODULATION ON KLYSTRON SIGNAL

Figure 5-39.—Slope detection for AFC operation.

al goes positive (1 to 2 to 3 on the audio
wave) the repeller voltage is made less
tive and the klystron frequency decreases
htly. This decrease moves the klystron
uency even further DOWN the cavity-
onse slope and the crystal output decreases
2 to 3 on the Beacon Crystal Output A). As
udio signal goes negative the klystron's re-
r voltage is made more negative and in-
ses the klystron's frequency. This increase
es the klystron frequency UP the cavity-
onse slope and the crystal output increases.
overall effect is that when the klystron
ency is below the cavity frequency the de-
d sine wave at the crystal output will be
OUT OF PHASE with the modulating sine
. The crystal output sine wave is labeled
figure 5-38.

ow consider that the klystron frequency is
int Y, above the cavity's center frequency.
e modulating audio sine wave goes positive
klystron's frequency is still decreased;
ver, since its frequency is above the cavity's
r frequency it now moves UP the cavity-
nse slope, and the crystal output increases.
everse is true when the audio sine wave
negative. The overall effect is that when
ystron frequency is above the cavity center
ency the detected sine wave at the crystal
will be IN PHASE with the modulating sine

e output of the crystal (either A or B) is
rough three stages of audio amplification
ppears at the phase discriminator in
ed form—that is, sine-wave A which is
ed as the polarity shown, is inverted in
lio amplifiers and is applied to the control
the phase discriminator as A'. Sine-
from the audio oscillator is applied to
ppressor grid. Note that A' and C are
phase with each other. Thus, the phase
inator knows that the klystron local
or is tuned low—that is, BELOW the
center frequency.

phase discriminator is arranged so that
not conduct unless both the control grid
suppressor grid are driven positive
neously. Otherwise, the tube remains
In figure 5-38 the sine waves (either
3') are fed to the control grid, and the
scillator sine-wave C is fed to the sup-
grid. When the crystal output is sine-
the control grid is driven positive as the suppressor grid is driven negative and the tube will not conduct. When the crystal output is sine-wave B both grids are driven positive simultaneously and the phase discriminator has an output.

The sweep generator functions to vary the klystron's frequency by varying the negative voltage on its repeller plate, as described in the thyratron AFC circuit just discussed. When there is no output from the phase discriminator the klystron frequency will be swept above and below the beacon cavity frequency (above and below 9,250 mc.) until the beacon crystal output is sine-wave B in figure 5-38. At this time the phase discriminator conducts and locks in the sweep so that the klystron's frequency varies only SLIGHTLY above and SLIGHTLY below the cavity frequency. From this point on, the action is identical with the control circuit of figure 5-37.

This system is called "absolute hunting" because no receiver signal is necessary to produce it, and the klystron is kept VERY close to a set frequency. In the case described, the beacon receiver signal will have a frequency of 9,310 mc. Since the local oscillator is controlled to 9,250 mc. the IF will be 60 mc. In contrast, the "frequency difference" system of automatic frequency control keeps the local oscillator tuned to the IF DIFFERENCE from the transmitter (and, therefore, the receiver) frequency, and will change as the transmitter frequency changes—always maintaining the IF difference. The "absolute hunting" system makes no allowance for frequency variation of the beacon signal that is received; therefore, the beacon transmitter must be very accurate in frequency.

DELAY SYSTEMS

The term DELAY SYSTEMS refers to special control circuits that are used in many electronic systems, particularly in radar sets. These circuits are used for the purpose of delaying a waveform, which, in turn, produces a delayed action. A knowledge of several of the basic circuits will prove helpful to you in gaining an understanding of the application and operation of delay systems.

Some of the more common types of electronic delay systems are the R-C, the phantastron, and the delay line (artificial lines).

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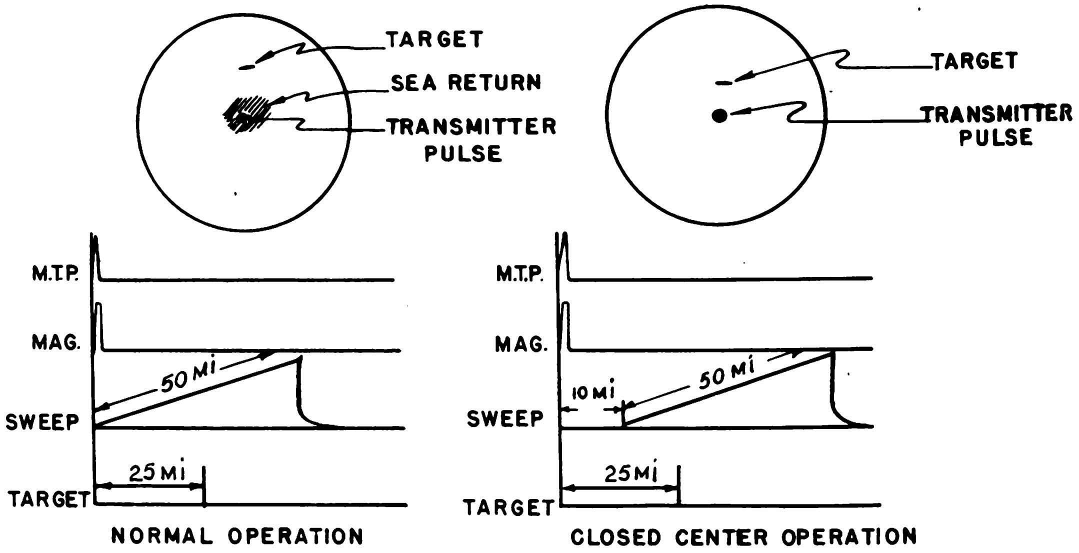

Figure 5-40.—Normal and closed center operation.

Purpose and Application

The PPI radar scope is a unit that makes use of various applications of different delay systems. Some of these are:

1. CLOSED CENTER OPERATION. In this operation the PPI sweep is started after the magnetron is fired. (See fig. 5-40.) As compared to normal operation, the targets appear to be moving in toward the center of the scope, hence the name CLOSED CENTER. This is used to eliminate the ground or sea return in the center of the scope. Also, it extends the range of the radar by the amount of delay that is used.

2. OPEN CENTER OPERATION. The magnetron fires after the sweep has started. (See fig. 5-41.) As compared to normal operation, the targets appear to be moving toward the outer edge of the scope. This action moves close-in targets toward the outer edge of the scope where they will occupy more space on the scope face. This spreads the target over more area and will improve target resolution. The effective range on this sweep is reduced by the amount of delay used.

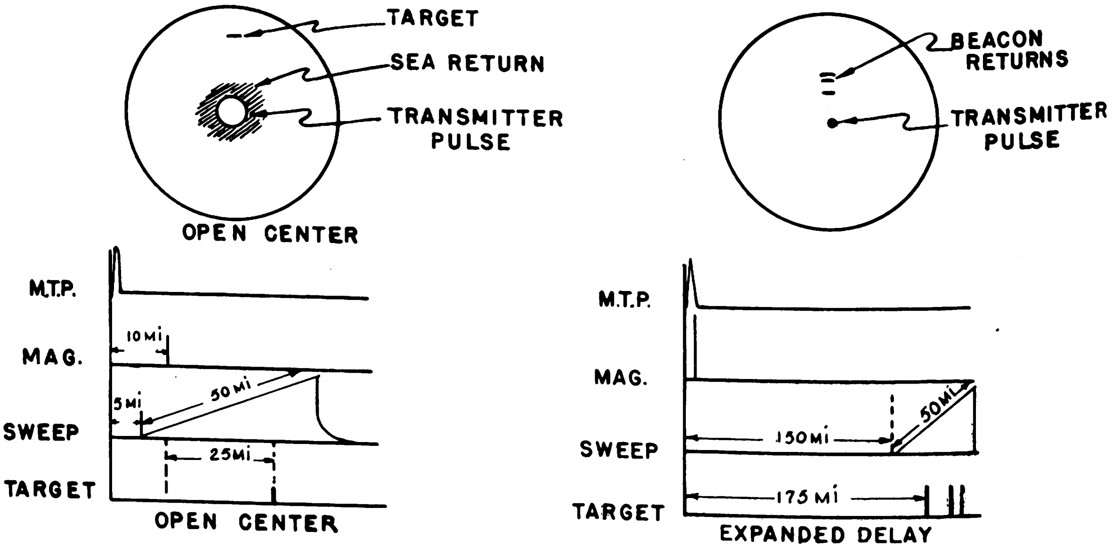

Figure 5-41.—Open center and expanded delay operation.

3. EXPANDED DELAY SWEEP. The start the sweep is delayed for a number of miles. ee fig. 5-41.) A much faster sweep speed is ed but sweep amplitude remains the same. is causes the distant returns to be spread they can be distinguished from each other. is also used to aid the operator in reading acon codes at great distances. The disvantage is that nothing can be seen on the ope prior to the time the sweep is started. l close-in targets will be obscured).

4. DELAY LINES. Delay lines may be used accurate short periods of delay such as deing the start of a PPI sweep. This enables sweep and transmitter to be triggered at same time. They are also used to generate ed pulses. Special types of pulse equipment, which pulses are transmitted at one location received at another, frequently use coded ses. These pulses are used for the purpose preventing signals of the same carrier frency, that contain similar pulses, from intering with the desired signal pulses. A com type of coding is that in which a group of es is used for each actual pulse. The pulses ach group are separated by accurate and unl time intervals. The means most fretly used for generating the pulses is a uit that contains the delay line (artificial smission line).

RC Delay System

his system may be used for open or closed er operation. It is used in some radar ems to permit the sweep to become linear e the transmitter is fired. The PPI sweep s at time zero, the R-C delay causes the mitter to be fired later, at a fixed time, the sweep has become linear.

UIT ANALYSIS

efer to fig. 5-42.) Since the grid is cond to a positive voltage, V_1 will normally ct heavily. Thus, plate voltage is low and ll be charged to this low voltage. The in- V_1 is derived from the multivibrator and is a negative square wave. The leadge of this square wave is time zero, and this time that the sweep generator is triggered. The leading edge of this square wave cuts off V_1 which was normally conducting. Plate voltage of V_1 cannot rise instantly because of the time required to charge C_2. Although C_2 charges at an R-C rate, during the first 10 percent of time the change in voltage is linear. V_2 is normally cut off by a voltage divider network in the grid circuit which places a minus 19.5 volts on the grid. The linear change in voltage at the plate of V_1 is coupled to the grid of V_2 causing it to go positive and overcome its bias. The delay is a function of the bias applied to the grid of V_2 and the rate of charge of C_2. When the bias is overcome, V_2 conducts and the blocking oscillator action produces a pulse output. A positive pulse output may be taken from the cathode and a negative pulse from across the plate load resistor. The blocking oscillator action in the grid circuit charges both C_2 and C_3 in a negative direction. This causes the plate voltage of V_1 to decrease and keeps V_1 from again triggering V_2 immediately. Before C_2 can again become positively charged to the point that it can trigger V_2, the short R-C in the grid of V_1 has allowed V_1 to conduct. Therefore, the circuit has returned to the static condition of V_1 conducting heavily and V_2 cut off.

The output of V_2 can be used to start the sweep and other timing circuits such as range-mark generators.

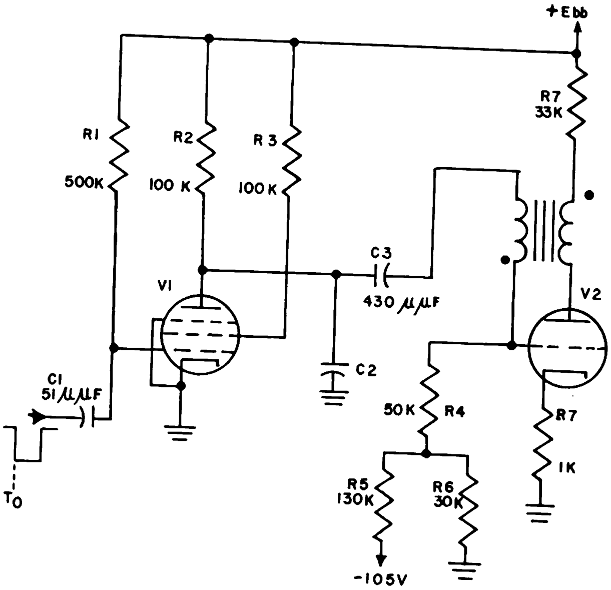

Figure 5-42.—RC delay circuit.

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Phantastron Delay System

A phantastron delay system may be used to produce a variable delay over the PPI range. In order to provide a delay over most of the full range of the PPI, it is necessary to use a cathode follower with the phantastron.

CIRCUIT ANALYSIS

The phantastron part of the circuit in figure 5-43 is similar to the one described earlier in this chapter and shown in figure 5-25. The phantastron is triggered simultaneously with the firing of the transmitter. The trigger input is applied to the cathode of V118 and the output of the phantastron is taken from the screen of V119. This output is a square wave that goes positive at the start of the delay and negative at the end. The output of the phantastron is applied to the trigger amplifier V121A. The end of the delay appears as a positive pulse at the plate of the amplifier. This pulse is coupled to the grid of the blocking oscillator V121B. This oscillator is biased negatively by the voltage divider network R183, R184, and a negative 105 volts; thus, it is normally cut off. Blocking oscillator action is initiated by the positive pulse from the trigger amplifier. The delayed sweep trigger is taken from the plate of the blocking oscillator V121B. A delay marker is taken from the cathode of the same tube. This marker appears as a movable range marker or ring on the PPI when the scope is in a nondelayed condition. This delay marker indicates the point at which the delayed or expanded sweep will start. (NOTE: Example—When 60 miles of sweep delay is desired, the delay marker is adjusted to aline with the 60-mile range marker. When the delay is switched-in, the sweep will start at the center of the scope after 60 miles of delay. Thus if a 30-mile sweep is used, the scope will cover 60 to 90 miles.)

Delay Line System

A simplified circuit for producing a rectangular pulse by the use of an artificial transmission line is shown in figure 5-44. The characteristic impedance of the transmission line is 2,500 ohms. The resistor, R_2, across which the output pulse is to be developed is equal to this

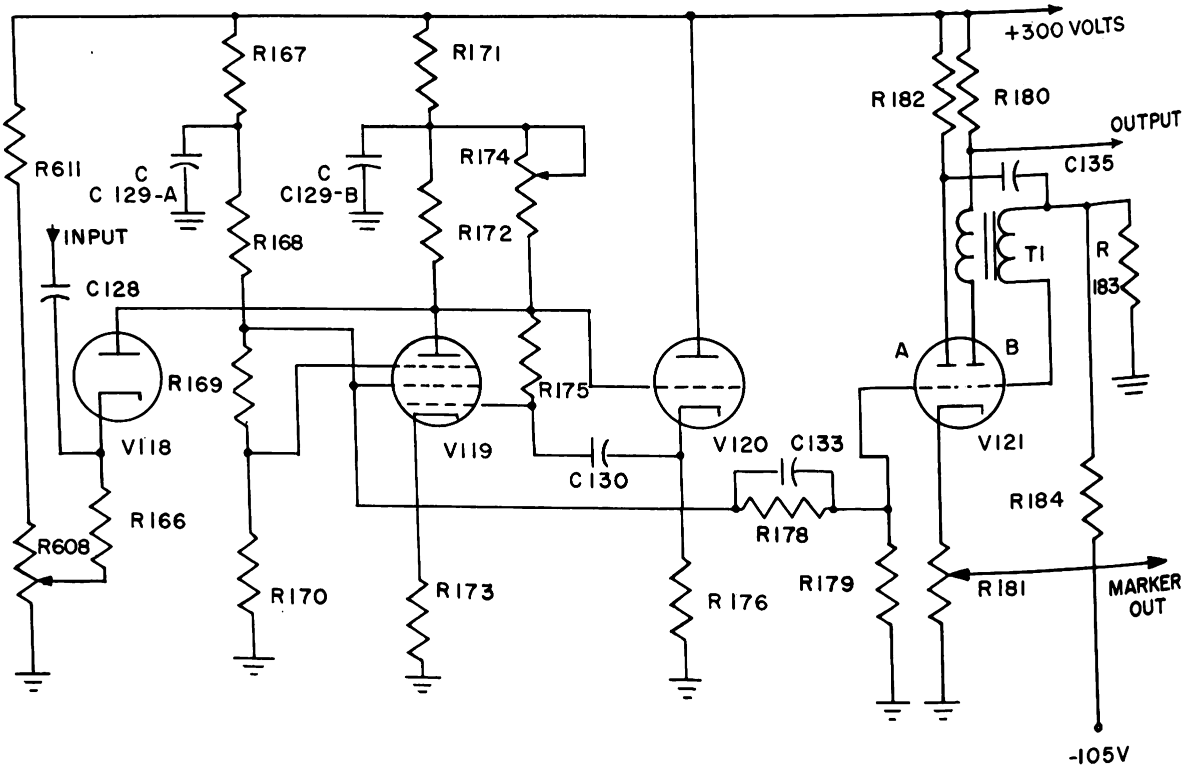

Figure 5-43.—Phanastron delay system.

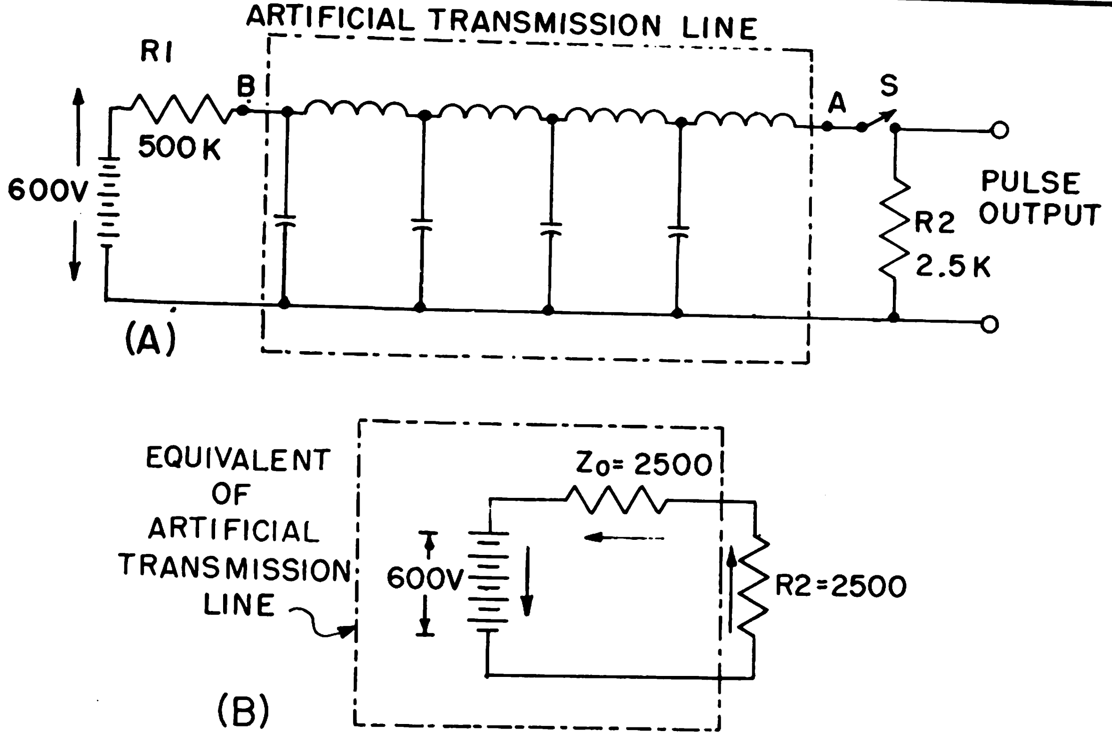

Figure 5-44.—(A) Simple circuit for producing a pulse from an artificial transmission line. (B) Equivalent circuit of artificial transmission line during discharge.

racteristic impedance. Resistor R_1, through ch the line is charged, is made very much ger than the characteristic impedance so that s an apparent open circuit during the discharge of the line. The capacitors are all charged 600 volts if switch S is left open for a suffint time. If the switch is closed after the line been charged, a current immediately starts low through R_2. The line may be considered battery with an internal impedance of 2,500 s during the discharge time (fig. 5-44 (B)). voltage across R_2 is one-half the voltage to ch the line was charged, or 300 volts, since the available voltage is lost across the 0-ohm internal impedance, Z_0. If the netk consisted only of capacitors, the discharge d follow an exponential curve, and the voltage ss R_2 would not be constant. However, the ctance and capacitance of the line are so gnated that the discharge rate is practically tant.

he discharge of the artificial line can be ined best as follows: At the instant that the h (fig. 5-44 (A)) is closed, the voltage at A falls to 300 volts. This can be looked upon as a traveling wave of -300 volts applied at point A to reduce the voltage there immediately from 600 to 300 volts. As the wave moves from A to B the voltage across the line is reduced from 600 to 300 volts. On reaching point B, the wave sees an open circuit, since resistor R_1 is very large. The wave is reflected without change in sign, and immediately reduces the voltage at point B from 300 volts to zero as the wave travels back to point A; and the remaining 300 volts across the line is canceled out. On reaching point A, the wave has reduced the voltage across all sections to zero, the wave itself disappearing because it is absorbed by a load which matches the characteristic impedance of the line. The pulse formed across R_2 by the line discharge lasts for the time required for the traveling wave to move from the switch end of the line to the open end and back.

Figure 5-45 shows an application of delay lines (artificial transmission line type) in a circuit that is used to generate coded pulses. A typical line of this type may be constructed by winding many turns of copper wire on a flexible tube of insulating material. This coil is first

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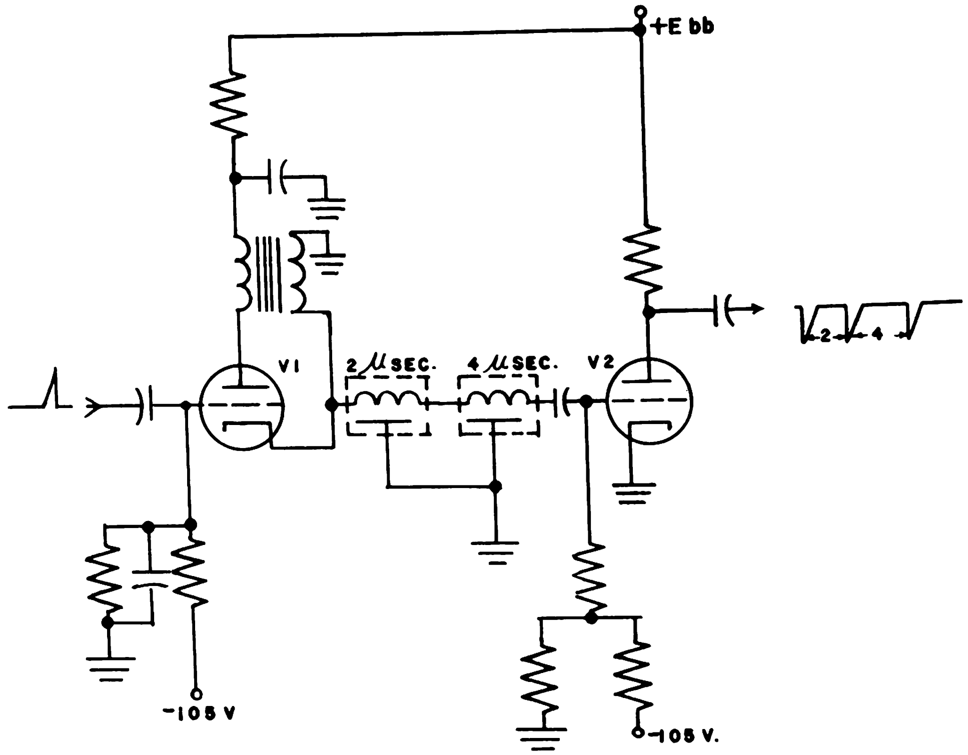

Figure 5-45.—Delay line coding circuit.

covered with a thin layer of insulation, and then a braided shield and another layer of insulation. The capacitance between the coil and the shield simulates the distributed capacitance of the actual transmission line and the inductance of the coil simulates the distributed inductance.

CIRCUIT ANALYSIS OF A CODING SYSTEM

The pulses to be coded are coupled to the grid of V_1 which functions as a blocking oscillator. The pulses, taken from the cathode of V_1, pass through the two delay lines. The pulse to be coded passes through the distributed capacity of the delay lines and appears at the grid of V_2 in time zero. The pulse also passes through the 2 μsec. delay line and is coupled to the grid of V_2 by the distributed capacity, 2 μsec. after time zero. The pulse passes through the 4 μsec. delay line and reaches the grid of V_2, 6 μsec. after time zero. For each pulse to the grid of V_1, there will be three pulses at the plate of V_2—the first pulse at time zero, the second at 2 μsec., the third at 6 μsec. The potentiometer keeps the distributed capacities above ground and serves as a means of balancing the amplitude of the three pulses.

CIRCUIT ANALYSIS OF A DECODING SYSTEM

A decoding system must be employed at the receiver to discriminate against undesirable pulses. A train of properly spaced pulses will provide the coincidence necessary for these to pass through the decoding circuits. Thus, there will be one pulse at the output of the decoder for each train of pulses applied to the input. Pulses that do not posses the proper time spacing will be eliminated by the decoder. A typical decoding circuit is shown in figure 5-46. In this circuit the pulses taken from the secondary of T_1 are applied to the three grids of V_1. These pulses are applied directly to grid 3, but because of the delay lines they will be delayed 4 μsec. to grid 2 and 6 μsec. to grid 1. V_1 is so biased that the application of any one or even two pulses, to the grids will not cause the tube to conduct. When three pulses are applied simultaneously to the three grids the bias is overcome and the tube conducts. This coincidence is graphically illustrated in figure 5-46. By referring to this graph you can easily see, as a result of the pulse

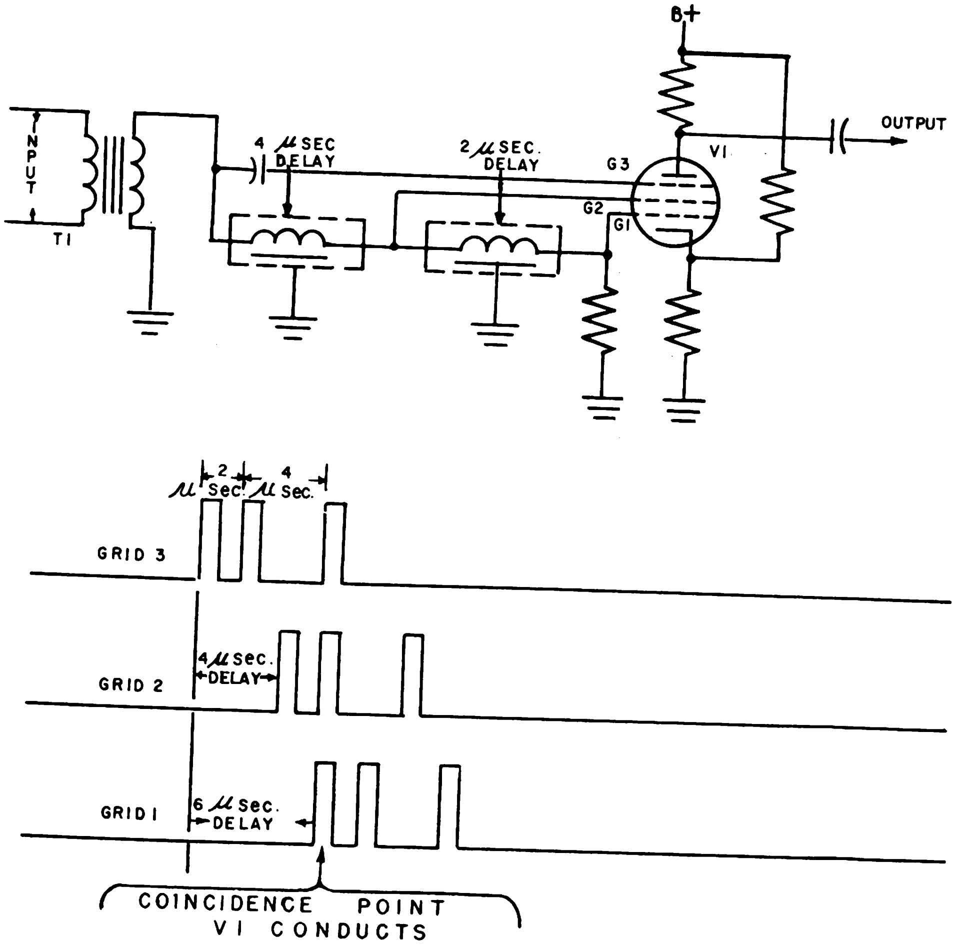

Figure 5-46.—Delay line coding.

g used, that at no time other than the co-
ice will more than one pulse be applied

MARKER SYSTEMS

ker systems are used to enable the radar
r to determine the location of targets
eat accuracy. This may be accomplished
sing visual guides to appear on the face
cope. These guides or markers will pro-
nge of distance to a target and azimuth
of a target. Some systems present ad-
information that gives the operator the
eight.

kers are also used on equipment other
dar, for example—electronic counter-
es, loran, oscilloscopes, and many
In these equipments, markers are used
to determine pulse width, pulse spacing, pulse amplitude, and various other functions.

Early radars depended on the linearity of the scope sweep for accuracy in range. A rough range scale was etched on a transparent plastic plate and this was placed on the face of the scope. Present-day radars obtain range marks from a range-mark circuit. This circuit consists of a stable oscillator that generates accurately spaced range marks which are used to modulate the electron beam in a PPI type scope. This type presentation causes intensity type markers to appear.

The type A scope may also utilize intensity type marks or the markers may be applied to the deflection circuits. The application of the marker to the deflection circuits causes pulse type markers to appear on the scope.

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Fixed Range Marker

This circuit uses a gated type ringing oscillator which produces range marks that are synchronized with the sweep. A circuit that illustrates this system is shown in figure 5-47.

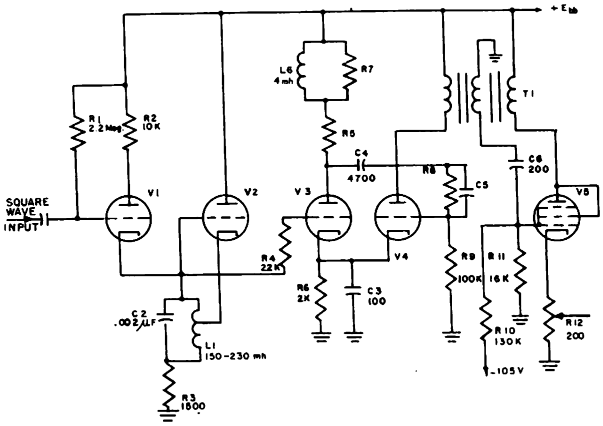

Figure 5-47.—Ringing oscillator range marker.

CIRCUIT ANALYSIS

The gating tube V_1, because of positive bias, is normally conducting and producing a steady flow of current through L_1. The flow of current through L_1 maintains a magnetic field around the coil; thus, the tank circuit composed of L_1 and C_2 cannot oscillate. Simultaneously with the starting of the scope sweep a negative square wave is applied to the grid of V_1, cutting the tube off and causing the magnetic field around L_1 to collapse. The collapsing of this field shock-excites the oscillator. The circuit will continue to oscillate throughout the duration of the negative square wave. The values of L and C, in the series-fed Hartley oscillator, are so chosen that the duration of each cycle of oscillation will be equal to the time between the desired range mark spaces. The leading edge of each negative oscillation will produce a range mark in the output of the circuit. V_2 replenishes the losses of the tank circuit, thereby maintaining the amplitude of oscillation.

The peaking amplifier V_3, that is normally conducting, is cut off by the oscillator's negative output. A high positive voltage at the plate of V_3 will be produced by the collapsing magnetic field around L_6. Oscillations across L_6 are prevented by damping resistor R_7, thereby preventing possible double range marks on the scope. Positive oscillation of the grid signal causes limiting to occur in the grid of V_3 due to R_4 in the grid circuit. Therefore, the negative-going portion is the only part of the input wave that has an appreciable effect on the plate current of V_3. The positive pulse output is coupled to the grid of V_4 through C_4 and C_5. C_4 functions as an ordinary coupling capacitor; C_5 in conjunction with R_8 acts as a fast coupling network. The leading edge of the output pulse from V_3 contains high frequency components; these are coupled through C_5 which bypasses R_8, therefore the complete leading edge of the output of V_3 is developed across R_9. This sharp rise in voltage on the grid of V_4 causes it to draw current charging the lower plate of C_5 negatively, since C_5 and R_8 have an R-C time of approximately 1 second. The charge due to grid current rapidly discharges through R_8 and returns the coupling circuit to a static condition.

If only C_4 were used to couple the sharp rise to the grid of V_4 when the grid drew current, the grid side of C_4 would go negative. Since the discharge path for C_4 is long, it would soon assume an average charge and the coupled signal would be reduced to minimum. The blocking oscillator V_5 is normally cut off by a fixed negative voltage on the grid. This circuit is triggered by the output of V_1 which is coupled to the grid of V_5 by transformer T_1. Positive range marks are taken from the cathode of V_5.

Movable Range Marker

Many present day radarscopes utilize the movable marker or RANGE STROBE. This system provides a continuously variable marker that may be used to aid the operator in quickly determining the accurate range of a target. Movable marker action may be incorporated in a radar system by using multivibrators or the phantastron time delay circuits previously discussed in this chapter. Another system whereby such marker action may be obtained is a timing circuit using a linear sawtooth and diode pickoff tube (fig. 5-48). This system is explained in detail in the following paragraphs.

CIRCUIT ANALYSIS

The sweep generator tube V_1, which is normally conducting, is cut off by the negative input square wave. When cut off, its plate voltage will rise at a rate determined by the sweep capacitor

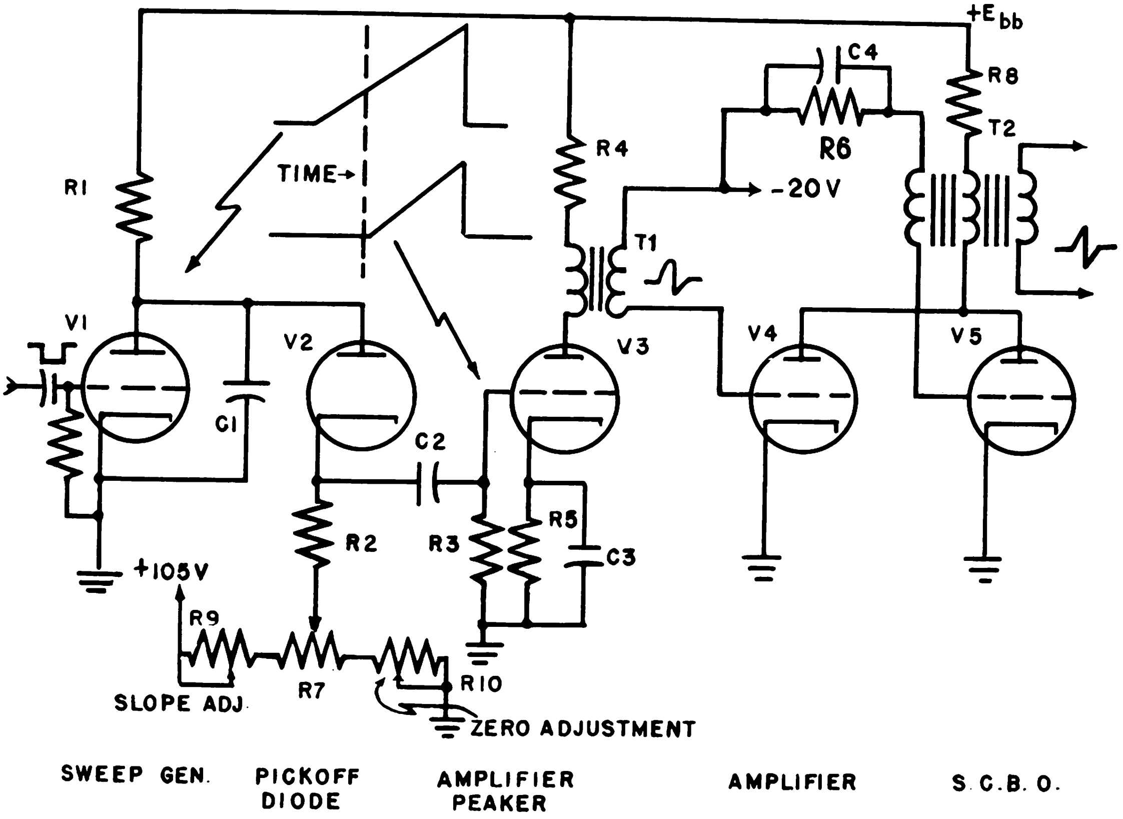

Figure 5-48.—Sawtooth type movable marker.

n order to obtain a linear sawtooth output ecessary to use either the first ten percent charge or to add a bootstrap circuit to the ɔth generator. This sawtooth waveform is d to the plate of V_2. V_2 is normally cut the positive voltage on its cathode. The ɔth rise applied to the plate of V_2 eventually ɔmes the cathode voltage and causes the to conduct. When this occurs the cathode rises at the same rate as the plate volt- d is applied to the grid of V_3. Tube V_3, e of the transformer T_1 in its plate cir- ıen functions as a peaker amplifier. The of V_3 is applied to the grid of V_4 and it to conduct momentarily. The current the plate winding of T_2, due to the con- of V_4, causes the single-cycle blocking ːor to cycle and produce the delayed pulse

duration of the delay depends upon the applied to the cathode of V_2; this voltage rmined by the position of the potentiometer arm of R_7. As the arm of the potentiometer is moved toward the more positive end, a higher voltage is then applied to the cathode of V_2 and more time is required for V_2 to start conducting, thus giving more delay before the pulse is produced. This delayed pulse is the movable marker that appears on the scope. Range is read from a mechanical counter or other indicating device which is mechanically coupled to the arm of the delay potentiometer R_7. This counter is calibrated by adjusting the zero adjustment R_{10} and the slope adjustment R_9. These potentiometers are positioned to provide the correct voltage across R_7 so that the delay that is provided, dependent upon the location of its arm, is correctly indicated by the counter.

Movable Height Marker

The linear sawtooth delay circuit (fig. 5-48) may be used as the timing system for measuring target height with radar equipment. In order

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for it to apply to movable height markers certain modifications must be made. The angle of elevation of the height finder antenna is referred to as Φ In the movable range marker (fig. 5-48), a fixed supply potential was used for the sawtooth generator, but when this circuit is used for height finding the supply voltage varies with the angle of elevation of the antenna. Thus, the slope of the sawtooth is proportional to sin Φ. In this application the counter or other indicator that is connected to the delay potentiometer indicates the target's height.

The curvature of the earth may be neglected when determining height at short or medium ranges. The relationship between delay time and target height, or the time when the height marker appears on the sweep, may be expressed as follows:

$$T = \frac{2H}{C \sin \Phi}$$

T equals time
H equals height
C equals speed of radio waves
Φ equals angle of elevation

Since the slope of the sawtooth has been made proportional to sin Φ, the time delay will be inversely proportional to sin Φ or, in other words, directly proportional to $\frac{1}{\sin \Phi}$ for a given diode bias.

QUIZ

1. In a phantastron delay circuit, the pulse width is normally increased by
   a. decreasing plate voltage
   b. increasing plate voltage
   c. increasing the value of the plate load resistor
   d. decreasing the value of the plate load resistor

2. In figure 5-34, to increase the count-down ratio,
   a. decrease bias on V3
   b. decrease value of C_1
   c. increase value of C1
   d. decrease value of C_2

3. In figure 5-1, increasing the size of C_2 will
   a. increase output frequency
   b. increase time of negative portion of waveform on the plate of V_2
   c. decrease frequency
   d. increase amplitude of waveform on plate of V_2

4. In figure 5-17, increasing R_2 will
   a. increase time of negative portion of output
   b. increase amplitude of output
   c. decrease amplitude of output
   d. increase time of positive portion of output

5. In a blocking oscillator, the tube is said to be blocked when the
   a. plate current reaches saturation
   b. grid bias has reached its most positive value
   c. grid is beyond cutoff and no plate current flows
   d. grid is beyond cutoff and maximum plate current flows

6. In a free-running multivibrator (See fig. 5-1), returning the grids to a positive potential will
   a. decrease frequency
   b. improve frequency stability
   c. increase amplitude of waveform at plate of V_2
   d. decrease amplitude of waveform at plate of V_1

7. In figure 5-37, when the klystron is operating at the proper frequency,
   a. V_1 will conduct periodically
   b. V_2 will conduct periodically
   c. the charge on C_6 will remain constant
   d. the charge on C_4 will remain constant

8. In figure 5-17, output frequency could be reduced to one-half the input by
   a. decreasing the size of C_2
   b. increasing the size of C_2
   c. decreasing the size of R_2
   d. increasing the RC time of R_1C_1

n figure 5-31, increasing input frequency will cause
a. voltage across R_1 to increase
b. voltage across R_1 to decrease
c. meter "M" to decrease its reading
d. charge on C_3 to decrease

multivibrator employs tubes as
a. electronic switches
b. amplifiers
c. detectors
d. oscillators

Vhat characteristic of the input pulse to a ositive step-by-step counting circuit can ary while the circuit is in operation without affecting the calibration of the equipnent?
a. Shape
b. Amplitude
c. Repetition rate
d. All of the above

requency division, as obtained by a mulivibrator, refers to the operation of a driven nultivibrator which is
a. driven at a submultiple of its free-running frequency
b. driven at a harmonic of its free-running frequency
c. synchronized to a harmonic of the driving frequency
d. synchronized to a submultiple of the driving frequency

he oscillatory circuit, which generates the narkers in most radar sets, is gated by a
a. sawtooth pulse
b. sine wave
c. trapezoidal wave
d. square wave

figure 5-1, increasing R_3 will
increase frequency
increase amplitude of waveform at plate of V_1
increase time of positive portion of waveform at plate of V_1
decrease amplitude of waveform at plate of V_1

multivibrator can be synchronized by plying
only positive pulses to the conducting tube
only negative pulses to the nonconducting tube
either positive pulses to the nonconducting tube or negative pulses to the conducting tube.
either positive pulses to the conducting tube or negative pulses to the nonconducting tube.

16. In a free-running single-swing blocking oscillator, the frequency is controlled by the
a. resonant frequency of the transformer
b. RC time in the grid circuit
c. type of tube used
d. size of the cathode resistor, when used

17. The type of PPI presentation used to read beacon codes of great distance is
a. open center operation
b. expanded delay sweep
c. normal sweep (no delay)
d. closed center operation

18. In a scale-of-two multivibrator, with positive pulses applied to both grids, the output frequency will be
a. twice input frequency
b. equal to input frequency
c. one-half input frequency
d. always higher than input frequency

19. An operating free-running multivibrator differs from an operating one-shot multivibrator in having
a. feedback between stages
b. two stages, alternately conducting and nonconducting
c. a synchronizing waveform required for operation
d. no equilibrium condition

20. In a multivibrator circuit the frequency-determining factors are
a. the types of tubes employed
b. the tank capacitors
c. grid capacitors and resistors
d. the values of the plate loading resistors

21. The cathode-coupled one-shot multivibrator is like the plate-coupled multivibrator in that
a. each stage is coupled regeneratively to the other stage in order to produce rapid action
b. feedback action is from the plate of each stage to the grid of the other stage
c. two stages return to their initial states of conduction automatically in order to be ready for the next trigger
d. feedback action of the second stage results from the cathode-to-cathode connection

22. A cathode follower may be added to a phantastron circuit to
a. provide a more linear delay
b. provide short delay periods
c. prevent the following circuit from loading the phantastron circuit
d. provide long delay periods

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CHAPTER 6

PROPAGATION OF RADIO WAVES

Certain fundamental concepts of propagation are included in *Basic Electronics*, NavPers 10087. This chapter is an extension of these concepts and at the same time includes sections on antenna location, forward scatter, and anomalous propagation.

The aim of this chapter is to more fully acquaint the AT with the mechanics of propagation, and the results of irregularities in the ionosphere.

In the study of this chapter (and also the chapter on antennas) it should be kept in mind that the subject matter field is broad and no attempt at complete coverage is made. Rather, only such background information that will be of help to the AT is included. In many instances, the AT will have the assistance of field engineers, or will at least have specific instructions on how to perform many jobs, and therefore will, in practice, need the information contained in this chapter only as a necessary background.

ELECTROMAGNETIC FIELDS IN SPACE

Wavefronts

At best, any device that is used to picture electromagnetic radiations in space is only a crude analogy of what is actually taking place. Water waves are frequently used as an analogy. Although electromagnetic radiations are commonly considered to be waves, under certain circumstances they behave in ways that make them appear to have some of the properties of particles.

In general, however, it is easier to picture electromagnetic radiations in space as being composed of horizontal and vertical lines of force oriented at right angles to each other. These lines of force are made up of a magnetic H, and an electric, E, component, and together make up the electromagnetic field in space. Strong fields are represented by many lines closely spaced; whereas, weaker fields are represented by fewer lines more widely spaced.

Energy from the transmitting antenna moves outward in ever-expanding spheres. A small portion of one of these spheres is called a WAVEFRONT, as indicated in figure 6-1. On this surface, the H lines are perpendicular to the E lines and both are perpendicular to the direction of propagation. A right-hand rule that ties these three quantities together is given in *Basic Electronics*, NavPers 10087. HORIZONTAL POLARIZATION means that the electric lines are horizontal with respect to the earth, and VERTICAL POLARIZATION means that the electric lines are vertical with respect to the earth. The choice of the electric field as a reference field results from the practice of measuring radio wave intensity in terms of ELECTRIC field intensity (for example, microvolts per meter).

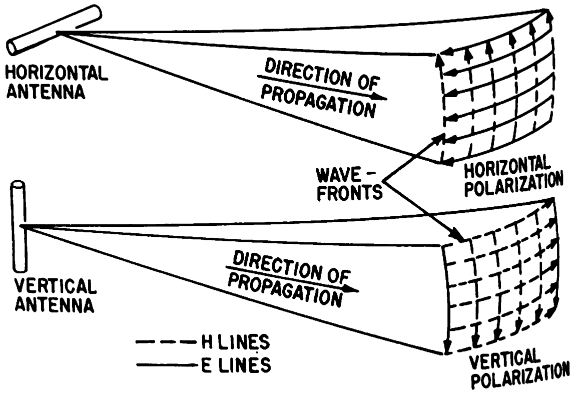

Figure 6-1.—Wavefronts showing horizontal and vertical polarization.

Directivity

en considering the energy radiated from an
a, an important concept is the directivity
antenna. The directivity of an antenna
measure of its ability to radiate energy
desired direction (or directions) and to
ss the radiation in other directions. The
is true of a receiving antenna, only in this
signals from the favored direction (or
ions) are received more easily than those
ther directions.

e radiation pattern, which is a good indi-
of the directivity of an antenna or antenna
is commonly plotted on polar graph paper
ay also be plotted on rectangular graph
It should be emphasized that when polar
nates are used, the resulting curve is
n actual picture or outline of the energy
ed by the antenna. It is rather an indica-
the relative (or actual) amount of energy
red to points on an imaginary circle a
n distance from the antenna, which is
y located at the center. The points where
asurements are taken are usually spaced
more degrees apart. Thus, the polar plot
ood picture in two dimensions of how di-
e the antenna is. It should be emphasized
hat the pattern is three dimensional, al-
the plot is commonly given only in the
ntal or vertical plane. The rounded pro-
s of the polar pattern are called LOBES
e indented portions, representing no (or
um) energy pickup in the test antenna, are
NULLS.

flection, Refraction, and Diffraction

n one is considering electromagnetic
in space (or, more specifically, the
ent of electromagnetic fields through
it is very important to understand clearly
meant by reflection, refraction, and dif-
. Because radio waves of short wave-
act somewhat like light waves (both of
re electromagnetic radiations), it is well
der these effects from the point of view
waves, which may be more readily ob-

TION

reflection of light is illustrated by the
in figure 6-2(A). When a ray of light (the incident ray) falls on a mirror surface, most of the light is reflected as shown. The angle of incidence is equal to the angle of reflection and lies in the same plane. When the incident ray is along the normal, the reflected ray is also along the normal. In order for pronounced reflection to occur, the object doing the reflecting must have the right type of surface and its size must be about one-half the wavelength of the incident wave. For example, dust particles will reflect light because they are large compared to the wavelengths of light. Actually, light is scattered out of the beam because of reflections from the particles.

Bright, polished surfaces will reflect light better than dull, rough surfaces. Large, smooth, metal surfaces that have high conductivity are good reflectors of radio waves.

As has been mentioned, reflection takes place only when the reflecting surface is large compared to one-half the wavelength of the incident wave, and smooth for an appreciable portion of one-half wavelength. Under these circumstances, the angle of incidence is equal to the angle of reflection. When these conditions are not met, scattering will occur. Scattering is a common occurrence. As a matter of fact, FORWARD SCATTER of radio waves in the troposphere and ionosphere (because of irregularities in density) is an important new method of radio wave propagation.

REFRACTION

When a light ray passes at an angle from a less dense to a denser medium, it is bent toward the normal; in other words, the angle of refraction is less than the angle of incidence. Likewise, when a light ray passes from a denser to a less dense medium, it is bent away from the normal; in other words, the angle of refraction is greater than the angle of incidence. Both of these conditions are shown in figure 6-2(B).

Refraction may be more easily understood if the incident ray is thought of as being a company of men marching, for example, four abreast (fig. 6-2)(D)) from a parade ground to a plowed field. The refracting medium is thought of as being the plowed field. In marching obliquely from the parade ground to the plowed field, each soldier in the front line will be slowed up as he crosses the boundary. Because the soldiers arrive at the boundary at different times, they will begin to slow up at different times, (No. 1 slowing up first and No. 4 last in each row).

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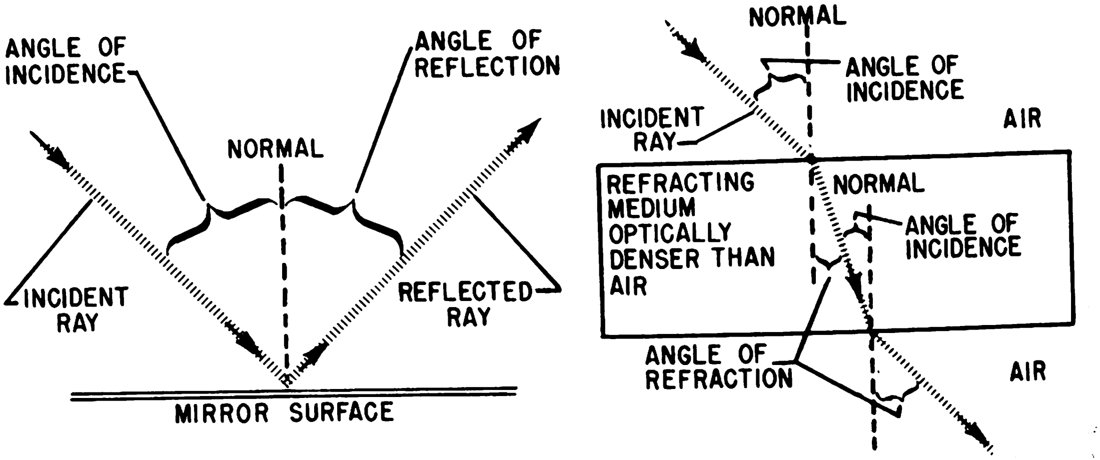
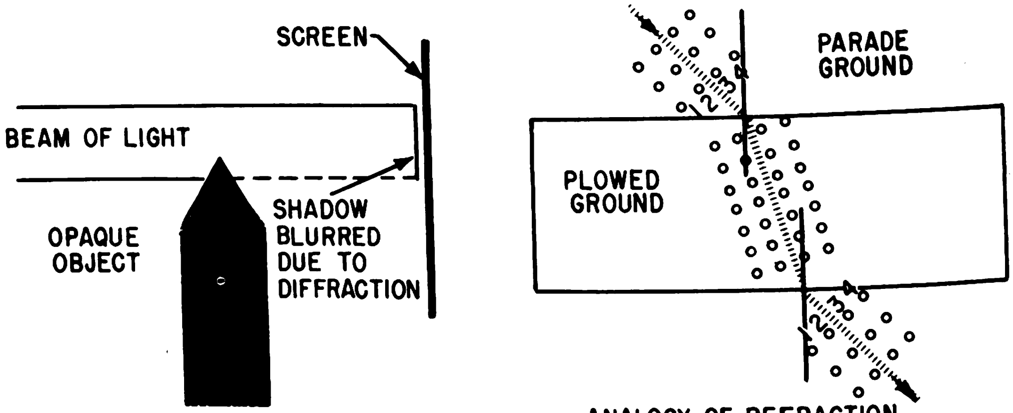


(A) REFLECTION

(B) REFRACTION



(C) DIFFRACTION

(D) ANALOGY OF REFRACTION OF LIGHT RAYS

Figure 6-2.—Reflection, refraction, and diffraction of light.

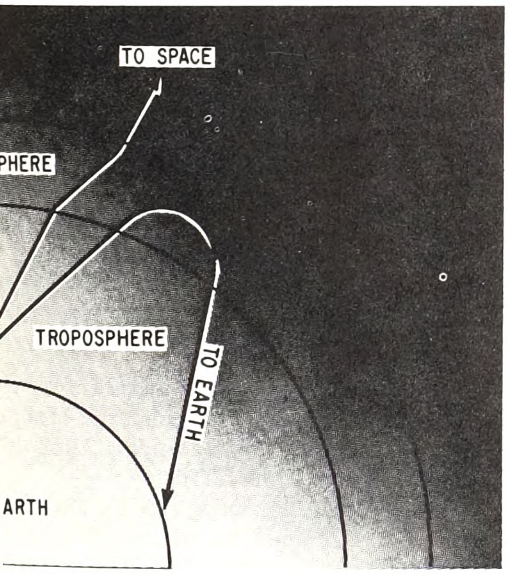
The net effect is a bending action, as indicated in the figure. Upon leaving the plowed ground, the reverse action takes place.

The INDEX OF REFRACTION is a term used to describe how much bending will take place in a given substance. The higher the index of refraction, the more the bending. Actually, the index of refraction is the ratio of the velocity of light waves in a vacuum to the velocity of light in the substance being considered.

In this illustration, the bending is considered to take place at the surfaces of the refractive medium. In the case of radio waves being refracted in the ionosphere the path is gradually curved because there is no sharp point of transition between layers of different densities. Those rays that make a large angle with respect to the horizontal along the earth may be refracted a small amount and pass on through the ionosphere to outer space; those that make a smaller angle will travel a greater distance in the ionosphere and may be bent to such an extent that they will return to earth. The net result is as if the wave had been REFLECTED back to the earth. A simplified illustration of ionospheric refraction is given in figure 6-3. A certain amount of refraction also takes place in the troposphere (below the ionosphere) because of the proximity of warm and cold air masses.

ACTION

raction of light occurs when a beam of asses over the edge of an opaque object. ergy is bent, or diffracted, around the the object, as indicated in figure 6-2(C). of a sharp outline being formed on the , the shadow will be blurred at the bot- cause of the bending of the light around rp object. Red light (long wavelength) into the shadow more than violet light wavelength).



e 6-3.—Refraction of radio waves in the ionosphere.

-frequency radio waves bend around -for example, mountains. At the higher ies, the bending is much less apparent. ugh these effects (reflection, refraction, action) have been listed separately, it is mmon for them to occur simultaneously. ion, there are other factors, such as ss due to absorption, changes in polari- nd reinforcement or cancellation due to s in signal path lengths. Therefore, it ntly difficult to discover exactly what ened to the radio wave during its passage transmitter to the receiver.

orward Scatter of Radio Waves

gation of radio waves by means of ienomena is relatively new; that is, the practical application of this principle to long-range communication is relatively new. Much basic research in this field is currently being conducted by the National Bureau of Standards, and much interest is being shown by industry and the armed services. Because of its great potentialities in the field of long-range communication in the VHF and UHF ranges, a brief mention of the subject is included in this chapter. Additional information may be obtained from current literature and from NBS publications.

Forward scatter is believed to be due to small variations in the composition of the atmosphere. This lack of homogeneity may be due to turbulences created by forces not clearly understood as yet. The net effect is a scattering of radio waves in all directions, especially in the forward direction of travel. By the use of powerful transmitters, highly directional antennas, and high-gain receivers, scatter signals from the troposphere may be received up to 600 miles and scatter signals from the ionosphere may be received at distances of between 600 and 1,200 miles. For tropospheric scatter, frequencies between 100 mc. and 10,000 mc. have been used; and for ionospheric scatter, frequencies between 25 mc. and 60 mc. have been used.

Although much work remains to be done in this field, it seems probable that VHF frequencies will become increasingly important in long-range communications; and for ranges up to 600 miles where tropospheric scatter is effective, the useful frequency range will be greatly extended.

IONOSPHERIC VARIATIONS

Variations in the ionosphere greatly affect the propagation of certain radio waves. It is therefore necessary to include a brief treatment of the variations that take place in the ionosphere. Although a degree of irregularity is characteristic of all ionospheric variations, nevertheless it is convenient to subdivide them into both irregular and regular variations.

Irregular variations cannot be accurately predicted in advance; regular variations follow a general pattern, and therefore may be predicted with a degree of accuracy.

Certain basic information on the ionosphere is given in *Basic Electronics*, NavPers 10087, and should be reviewed at this point.

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Irregular Ionospheric Variations

SUDDEN IONOSPHERIC DISTURBANCE

This type of disturbance in the ionosphere is caused by radiation from solar flares that produce intense ionization in all layers of the ionosphere in daylight areas.

Frequencies above 1 or 2 mc. (depending on the intensity of ionization) are largely absorbed in the heavily ionized D layer. Higher frequencies may be used for short-distance communications, and lower frequencies (which do not penetrate the D layer) may be used for long-distance communications.

IONOSPHERIC STORMS

These so-called magnetic disturbances (magnetic storms) occur about 18 hours after sudden ionospheric disturbances. The upper ionosphere expands and becomes diffused, the effects being more severe near the poles and less severe near the equator. They may last from a few minutes to several hours; the intensity then diminishes, and the effects disappear in a few days.

During the peak of the storm and for a period thereafter it may be necessary to use lower than normal frequencies, especially in high latitudes.

SPORADIC DISTURBANCE IN THE E LAYER

Frequently, ''clouds'' of abnormal ionization occur at the approximate altitude of the E layer. The occurrence is spotty both in time and place. This results in excellent reception within the normal skip distance, and occasionally long-distance communication may be obtained above 60 mc. The frequency may have to be lowered to maintain short-skip communications.

SCATTERED IRREGULARITIES IN THE IONOSPHERE

Scattered irregularities in ion density may cause scattered reflections and therefore signal fading because of varying phase relations resulting from variation in signal path lengths. It is a situation that must be tolerated.

EFFECT OF METEORITE TRAILS

Large numbers of meteorites enter the upper atmosphere during the course of a day. A portion of the energy released as these particles are slowed down is utilized in ionizing the atmosphere. The volume of the atmosphere ionized by one of these particles is very large, considering the size of the particle. It may be several feet in diameter and perhaps a mile or more in length. Even though recombination of the ions occurs very rapidly, nevertheless ionization often lasts long enough to cause radio stations to be heard that would not normally come through.

Research is currently being done in this field, and perhaps the effect of meteorite trails on propagation may, in time, be used to great advantage.

Regular Ionospheric Variations

ELEVEN-YEAR SUNSPOT CYCLE

Periods of maximum sunspot activity occur 11 years apart. For example, the last period of maximum activity was during 1958-1959; the next one will be 1969-1970.

During these periods, the F_1 and F_2 layers, especially, increase in density and height. In general, higher operating frequencies are necessary for long-distance communications.

SEASONAL VARIATIONS

During the summer months the height of the F_2 layer is increased, and during the winter months it is decreased. During the winter months the ionization density rises earlier in the day and reaches a higher value than in the summer months, and the pre-dawn ion density reaches a lower value. The F_1, E, and D layers reach lower maximum densities in winter.

Medium high frequencies are used for long-distance, winter communication, and the lower high frequencies for medium-distance communication.

TWENTY-SEVEN-DAY SUNSPOT VARIATIONS

These disturbances accompany sunspot activity that occur every twenty-seven days. This interval is the time required for the sun to complete one revolution about its axis. The effect dio transmission is essentially the same as of sudden ionospheric disturbances, which reated under irregular ionospheric varia- earlier in this chapter.

NAL (DAILY) VARIATIONS

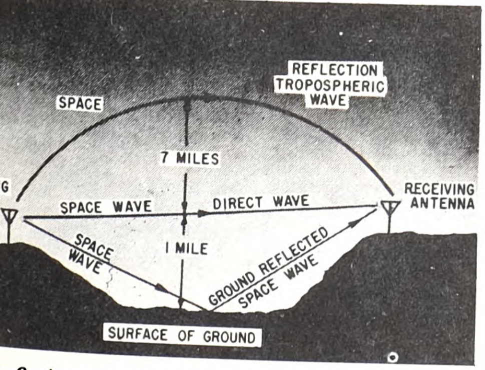
ring the daylight hours the density of the ers increases; the thickness of these layers increases during this time. During the e of the day, the F layer splits into the d the F_2 layers. The ion density of the ver varies with the vertical angle of the nd the ion density of the F_2 layer in- s to a peak somewhat later in the day. e ion density of the E layer varies with rtical angle of the sun, and the height ns approximately constant; the E layer is veaker at night.

e D layer appears after dawn, and the nsity varies with the vertical angle of the t disappears at night. The D layer ap- between 40 and 50 miles above the surface.

ND- AND SKY-WAVE PROPAGATION

Ground-Wave Propagation

nd-wave propagation does not involve osphere. For convenience, it may be into three, or possibly four components. surface-wave component (fig. 6-4) is the ent that moves along, and in, the sur- he earth. The field strength of this com- diminishes rapidly with distance, much apidly than the components that move free space. Absorption by the earth in- with increase in frequency, and there- y relatively low frequencies may be used for long-distance communications. A vertically polarized ground wave is attentuated less than a horizontally polarized ground wave because a horizontally polarized ground wave is short circuited by the earth and is rapidly attenuated. That portion of the vertically polarized surface wave that is directly above the earth is diffracted or bent toward the surface of the earth in such a manner as to give the wave a horizontally polarized component. This diffraction effect further causes the wave to bend along the curvature of the earth, thus extending the range of coverage.



e 6-4.—Ground-wave propagation.

Under certain conditions (for example, in communications between low-flying aircraft that are relatively close together) there may likewise be a ground-reflected component, as shown in the figure, that will reach the receiving antenna. Because of the longer path of the ground-reflected wave, it may arrive out of phase with the direct wave or the refracted tropospheric wave.

The direct-wave component passes directly from the transmitting antenna to the receiving antenna. Although the path of the direct wave is indicated by a straight line, there is a slight amount of refraction in the atmosphere because of small variations in density. In general, this effect will extend the radio horizon about 15 percent greater than the straight-line distance to the horizon.

The tropospheric wave component is the component that is refracted in the troposphere. Changes in atmospheric density at heights of several thousand feet cause considerable bending of radio waves, especially at the higher frequencies, and therefore considerable distances at frequencies above 50 mc. may be achieved. Tropospheric forward scatter as a fairly reliable means of communication up to 600 miles has been mentioned earlier in the chapter. Temperature inversion (treated later in the chapter) is the principal cause of tropospheric refraction.

Sky-Wave Propagation

For high-frequency (3 mc.-30 mc.) communication over great distances, sky-wave propagation is used. The radiated energy is directed toward the ionosphere and is refracted back to the earth at distances of hundreds or even thousands of miles. When multihop transmission is used, a sequence of refractions in the

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ionosphere and reflections from the earth occur. Because of variations in height and density of the ionosphere, sky-wave propagation is not considered as reliable as ground-wave propagation. However, much greater distances may be covered by means of sky-wave propagation than by ground-wave propagation.

The mechanics of sky-wave propagation is not completely understood. However, progress is continually being made in this study, particularly in the effects of sunspots and other phenomena on propagation.

Figure 6-5 is a simplified illustration of sky-wave propagation, showing day and night propagation at two angles of radiation.

As may be seen in the illustration, the lower the angle of radiation the further will be the distance from the antenna to the point where the energy first returns to earth. Thus, for single-hop transmission for great distances it is desirable to have low-angle radiation. At night, the refraction takes place in the F layer; and, for equal angles of radiation, the distance covered in one-hop transmission is much greater than it is during the day when the refraction may take place in the E layer.

Although they are not readily apparent in the illustration, the following facts are important in sky-wave propagation:

1. The greater the intensity of the ionization in a given layer the greater the refraction, or bending, of a wave at a given frequency
2. The lower the frequency (longer wavelength) the greater the refraction of a wave in a given layer for a given intensity of ionization.

Thus, it may be seen that the critical angle (the angle of propagation beyond which the RF energy passes through the ionosphere and does not return to the earth) may be very great if the intensity of the ionization is high and the frequency is low. Conversely, the critical angle may be very small if the ionization intensity is low and the frequency is high.

If a low angle of radiation is employed at night (ray 3, fig. 6-5), the SKIP DISTANCE (distance from the antenna to the point where the wave returns to earth) is likely to be very great. Therefore, there will be an area around the transmitting antenna in which no sky wave will be returned. This is the SKIP ZONE, as far as sky waves are concerned.

When multihop transmission is used, very great distances may be covered. The geometry of multihop transmission is relatively simple and satisfying if one is content with a less rigorous analysis of the situation. It is easy to think of the wave leaving the antenna at some angle less than critical, being refracted in the ionosphere back to the earth at the end of the skip distance, being reflected back to the ionosphere, being refracted back, and so on. In reality, however, the situation cannot be explained so easily.

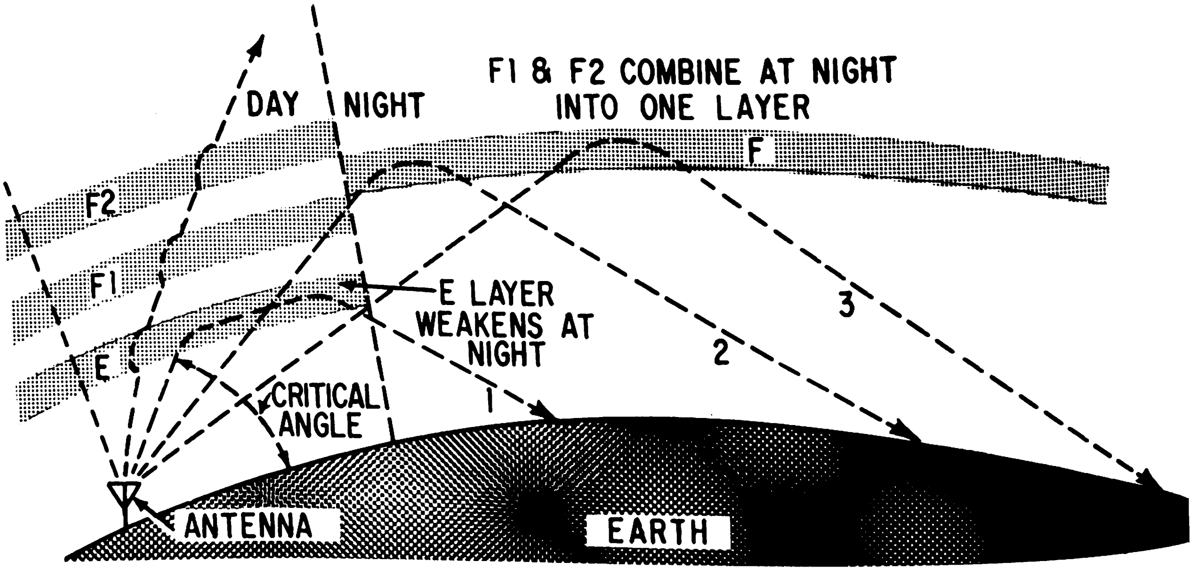

Figure 6-5.—Simplified illustration of sky-wave propagation.

of all, a second or third skip zone does
Also, it is apparent that only the con-
the ionosphere at the transmitter and
has any bearing on satisfactory trans-
It would seem that according to the
of the transmission path the condition
osphere between the transmitter and
would also be very important. Further
may shed new light on multihop trans-

SING THE PROPER FREQUENCY

Frequency Bands

6-6 shows the frequency distribution
spectrum. The figure also indicates the
hich portions of the RF spectrum are
example, the radar bands extend from
the EHF band; the commercial tele-
nnels cover portions of the VHF and
s; and communications make use of
bands except the EHF. The approxi-
nces covered are also indicated, as
e types of transmission lines com-
d and the types of interference com-
rienced.

e Propagation Versus Frequency

been stated, the higher the frequency
ssion the lower must be the angle of radiation for effective transmission. This results from the fact that high-frequency radiation passes through into space and is effectively lost when the angle of radiation is high. Low-frequency radiation may be returned to earth even if it is radiated vertically upward (90° radiation angle). As a matter of fact, the effective height of the ionosphere can be determined by directing low-frequency pulses vertically upward toward the ionosphere and measuring the time lapse between the transmitted pulse and the echo. Knowing the velocity of radio waves, it is relatively easy for one to compute the effective distance.

If the frequency is increased while the height measurements are made, it will be found that above a certain frequency (the critical frequency) echoes are not returned to earth. However, if the radiation angle is reduced sufficiently, echoes will be returned to earth at some distance from the antenna. The distance depends on the height and density of the ionosphere.

For the E layer, the critical frequency is from 1 to 4 mc., depending on the ion density of the E layer. For the F_2 layer (daytime), the critical frequency is of the order of 2.5 mc., and for the F layer (night), it is of the order of 12.5 mc.

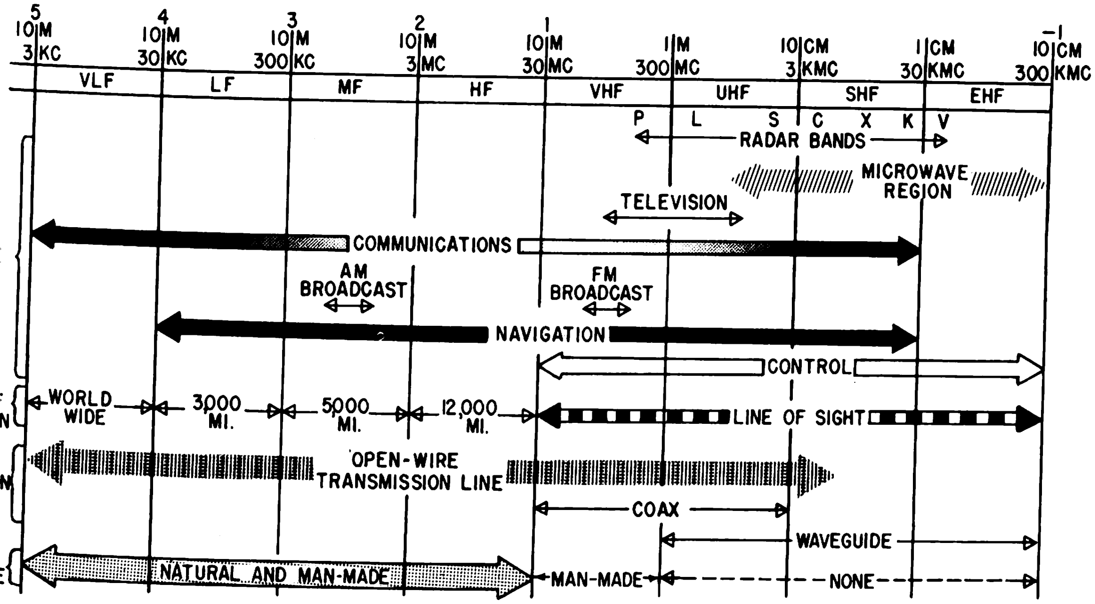

Figure 6-6.—RF spectrum.

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Maximum Usable Frequency

Because less energy is absorbed out of high-frequency radiation during transmission, it is desirable to know the MAXIMUM USABLE FREQUENCY (MUF) that may be employed in transmission. Higher frequencies will pass through the ionosphere and will be lost to the communication circuit, and lower frequencies will be seriously attenuated in the ionosphere.

Data on the maximum usable frequency is collected by the National Bureau of Standards and is made available to the Navy in the publication, *Basic Radio Propagation Predictions*.

Lowest Useful Frequency

As the radiated frequency is reduced below the MUF, more and more energy is absorbed from the wave and is lost, as far as communication is concerned. This absorption occurs principally in the D and E layers, which are maximum during the daylight hours, especially for frequencies between 500 kc. and 2,000 kc. At a certain frequency (THE LOWEST USEFUL FREQUENCY (LUF)) the signal strength reaching the receiver barely overrides the background noise. Frequencies below this cannot override the noise and therefore serve no useful purpose.

Optimum Working Frequency

Because both the height and the density of the various layers of the ionosphere may change from hour to hour, it is not possible to predict the exact MUF for each hour. Predictions are based on averages made over a long period of time. Therefore, it is necessary to choose an operating frequency that will not shift above the MUF when sudden changes in the ionosphere occur. This frequency (some 15 percent below the MUF for F_2 transmission) is called the OPTIMUM WORKING FREQUENCY. When the lowest usable frequency is only slightly below the maximum usable frequency, the 15 percent figure may not apply.

ANOMALOUS PROPAGATION

Anomalous means a deviation from the general rule or a condition that cannot be easily classified or explained. In other words, anomalous propagation is a general term applied to all nonstandard radar or radio propagation. It is the net effect of certain variables that may result in extremely long or short ranges (particularly in radar); oftentimes changing from one to the other or back to normal in a matter of a few hours or a few days. These abnormal or subnormal ranges (resulting from anomalous propagation) may, on occasion, cause some confusion and misunderstanding.

Anomalous propagation is caused by changes in atmospheric conditions, principally in temperature and moisture content. Under normal conditions, radar energy travels in a path very nearly that of line-of-sight, with possibly some bending. In general, surface-search antennas are so designed that the energy is directed along the surface in a fairly concentrated beam. However, there is a limited amount of vertical coverage.

At radar frequencies some of the energy is lost because of high-angle scattering, and under normal conditions some of the energy that is propagated along the surface will be attenuated in a regular manner by the passage through the air. Under abnormal conditions, other effects may be observed.

Under normal, or standard, conditions the temperature of the atmosphere decreases slowly and regularly from the surface of the earth to the higher altitudes, and the moisture content varies in much the same manner.

When a warm body of air is present over a cool body of water, the evaporation of the water from the surface produces a decrease in temperature and an increase in moisture concentration near the surface. At a certain height above the surface, depending on the height of the body of warm air, the temperature will be greater and the moisture content will be less than at the surface. This results in a sharp temperature inversion and a pronounced decrease in moisture content at the top of the layer of warm air. Under these conditions, radar waves are refracted more than normal and tend to follow the surface of the water. Therefore, surface targets and low-flying aircraft may be detected at greatly increased ranges because of the "duct" formed between the water and the cool air mass.

For example, off Tsingtao, China, a cruiser actually detected an aircraft carrier at 120 miles and was even able to count the planes as they were launched from the carrier deck.

Radar surface coverage can likewise be adversely affected, as for example when the "duct" ned in the atmosphere itself instead of he surface, particularly when the duct upward. If meteorological conditions are at the air is cool and moist up to a altitude and above this there exists a ody of air, temperature inversion will e be present. However, the "duct" rmed in the strata of warm air will have nection with the surface of the water. If uct" tilts upward, it is possible that will be trapped in the "duct" and will increase in high-angle coverage but a reduction in low-angle or surface cov-

eries of these "ducts" exists during cer-riods of the year at a location about 60 the coast of southern California. Their however, is to establish phantom targets y be plotted. They appear to be moving dly as 60 knots.

EFFECT OF ANTENNA SITE

ld you be required to set up a VHF or ommunication station at a forward base ome training location, careful attention be given to antenna location. In general, rules apply—(1) locate the antenna as om the ground as is practical; (2) in nstallations locate away from manmade (3) locate on the highest ground in the 4) if possible, choose a site that is flat, no hills or forests.

ical considerations may not permit com-with all these general rules; however, the relates to antenna height is most im-When vertically polarized transmission a water is used, antenna altitude is less nt in the lower VHF frequencies. But, igher VHF and all UHF frequencies the should be elevated. When horizontal tion is used, the higher the antenna r—at all frequencies.

DAR RANGE CONSIDERATIONS

section on radar signals does not, in sense, belong in this chapter, "Propa-Radio Waves." However, it is d important that certain factors con-radar signals be presented before the information on production and of radar signals. Production and radiation of radar signals is covered in the next three chapters. The information that will now be presented will be a review of some of the characteristics of the signals that will be utilized in the coverage given to waveguides, microwave techniques, and antennas.

The principal characteristics of the transmitted radar signal are—(1) pulse width; (2) pulse-repetition frequency; (3) beamwidth; and (4) power relation.

Pulse Width

A pulse of energy is radiated each time the radar's magnetron is permitted to oscillate. The duration (time) of that oscillation is the pulse width. Figure 6-7 depicts the radar pulse as a rectangular envelope; in actuality the pulse is many cycles of RF energy released by the magnetron for that duration of time.

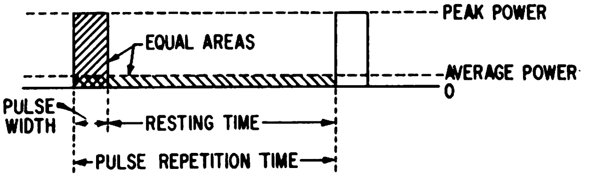

Figure 6-7.—Relationship of peak power and average power.

When the magnetron begins oscillation, the pulse energy begins to travel away from the antenna. If the pulse is 2 microseconds long, the leading edge of the pulse will have travelled approximately 2,000 feet (actually somewhat less) by the time the pulse has ended; therefore, objects within the range of 1,000 feet cannot be detected by the radar. The detection of objects slightly more than 1,000 feet away depends on (1) the shape of the trailing edge of the transmitted pulse; (2) the recovery time of the TR switching device; and (3) the recovery time of the receiver circuits. All of these affect range, but the factor that absolutely limits the minimum range of a radar is the pulse width.

Figure 6-7 depicts the transmitter pulse as having sharply defined leading and trailing edges; actually the transmitter continues to send out energy for a short time after the pulse has essentially ended. This INCREASES (lengthens) the minimum range at which targets can be detected. The TR switching device, being a gas tube, requires a certain amount of time to de-ionize; this further limits the minimum

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range. Recovery time of the receiver is the time required (1) to remove cutoff voltages that are applied to the receiver circuits during transmit time, and (2) to remove the voltages caused by high power leakage into the receiver. Removing receiver cutoff voltages is called "dunking."

Pulse width also determines target discrimination—that is, the ability to separate targets that are in close proximity. Two targets in line with the radar antenna appear as one thick target on the radar-indicator screen if the distance between the targets is less than the distance corresponding to the width of the transmitted pulse. For good target resolution the pulse width must be small.

Pulse-Repetition Frequency

Sufficient time must be allowed between transmitted pulses for an echo to return from any target located within the maximum workable range of the radar. This necessary time interval fixes the highest frequency which can be used for the pulse-repetition rate. Factors that limit the minimum repetition frequency of a given system are (1) screen persistence of the cathode-ray tube, and (2) speed of antenna motion.

When the antenna unit is rotating, the beam strikes a target for a relatively short time. During this time a sufficient number of pulses of energy must be transmitted in order to return a signal which will produce a lasting indication on the indicator screen. Therefore, with a given pulse width and peak power, persistence of the screen and the rotational speed of the antenna determine the lowest repetition rate that can be used.

In a radar in which the entire time interval between transmitted pulses is used to produce the sweep on the indicator, the repetition frequency must be highly stable if accurate range measurement is desired. If the PRF is not stable, the targets will not appear at the same place on successive sweeps. The indicator sweep starts at the same time as the pulse; therefore, the target would appear sooner or later than on the preceding sweep if the pulses occur at varying intervals of time. When this occurs, the target will not be definite but will be blurred. Since the indicator screen will normally have a relatively long persistence, successive traces should appear in exactly the same position to avoid blurring.

In an airborne radar most but not all of the rest period between pulses is used to produce the sweep on the indicator. This allows a less rigid adherence to the PRF. For example, if the rest period is 1,000 microseconds, only 998 microseconds may be used.

Beamwidth

The pulse from a radar is not projected into space in a pencil-thin line, but fans out to form a lobe. Figure 9-6 of chapter 9 depicts a lobe pattern with its half-power points. The beamwidth can be defined as the angle formed between the antenna and the half-power points of the lobe pattern. This angle contains the greatest percentage of energy in the pulse.

Beamwidth is a function of antenna gain. By increasing the antenna gain, more power is transmitted along the axis of the antenna because the beamwidth narrows. The gain of a radar antenna depends on the size and construction of the antenna and the operating frequency. The higher the operating frequency, the greater the antenna gain for a given size, and the narrower the beam. Therefore, the range of a radar can be increased by increasing antenna gain. This occurs because all of the usable energy of the pulse is contained in a narrower beam and targets reflect more energy from each pulse. However, a narrow beam may necessitate (1) a slower antenna rotation or (2) a higher PRF. These prevent areas from being skipped by the beam.

The beam from a radar has vertical width as well as horizontal width, and the type of antenna used determines the beam shape. Search radar beams have a wider horizontal than vertical width. Some beams are very narrow in vertical width, and in order to search enough vertical distance (altitude) the antenna is caused to move up and down (nod).

Power Relation

A radar transmitter generates RF energy in the form of extremely short pulses and is then turned off between pulses for comparatively rvals. The useful power of the trans- : that contained in the radiated pulses rmed the PEAK POWER of the system. s normally measured as an average er a relatively long period of time. radar transmitter is resting for a time long with respect to its operating time, ge power delivered during one cycle of is quite low compared to the peak ailable during the pulse time.

inite relationship exists between the power dissipated over an extended time and peak power developed during e time. The time of one cycle of is the reciprocal of the repetition , T = 1/f. Other factors remaining the greater the pulse width the higher ige power; and the longer the pulse- i time the lower the average power.

$$\frac{\text{ige power}}{\text{power}} = \frac{\text{pulse width}}{\text{pulse-repetition time.}}$$

ieral relationships are shown in figure

operating cycle of the radar trans- n be described in terms of the fraction il time that the RF energy is radiated. e relationship is called the duty cycle oe represented as

$$\frac{\text{se width}}{\text{se-repetition time}} = \text{duty cycle.}$$

ple, a 2-microsecond pulse repeated e of 500 times per second represents le of 0.001, since the time for 1 cycle econd, or 2,000 microseconds:

$$\frac{2}{2{,}000} = 0.001 = \text{duty cycle}$$

e, the ratio between the average peak power may be expressed in ie duty cycle:

$$\frac{\text{verage power}}{\text{eak power}} = \text{duty cycle}$$

In the above example it may be assumed that the peak power is 200 kilowatts. Thus, for 2 microseconds, 200 kilowatts of power are available, while for the remaining 1,998 microseconds zero power is available.

Since

average power = peak power x duty cycle

Then

average power = 200 x 0.001 = 0.2 kilowatts

These relationships are shown in figure 6-8.

High peak power is desirable to produce a strong echo over the maximum range of the equipment. Low average power enables the transmitter tubes and circuit components to be made smaller and more compact. Thus it is advantageous to have a low duty cycle. The peak power which can be developed is dependent upon the interrelation between peak and average power, pulse width and pulse-repetition time, or duty cycle.

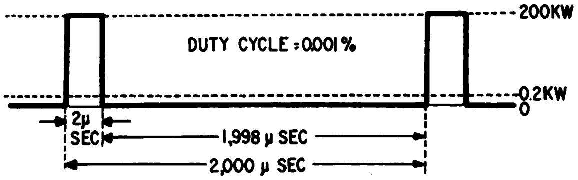

Figure 6-8.—Duty cycle.

APPLICATION CONSIDERATIONS

The job for which a specific radar system is designed will determine all of its operating characteristics, but some factors appear constantly in all pulse-type considerations. An "ideal" pulse would (1) be very short in pulse width to detect near targets and separate targets that are close together; (2) have high peak power and high average power for maximum range; (3) have a narrow beamwidth for accurate azimuth location of target and stronger signal echo; and (4) have as its indicator a high-persistence CRT to permit a low PRF.

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QUIZ

1. Ionospheric storms (magnetic storms), which occur about 18 hours after ionospheric disturbances, have their greatest effect on communications
   a. on direct transmission
   b. at the equator
   c. at the North and South Poles
   d. on anomalous propagation

2. For a given amount of ionization, the bending (refraction) of radio waves in the ionosphere
   a. becomes greater as frequency is increased
   b. remains the same regardless of frequency
   c. becomes less as frequency is increased
   d. depends on the altitude of the ionized layer

3. Speed of antenna rotation and CRT persistence limit the
   a. minimum pulse-repetition frequency
   b. maximum pulse-repetition frequency
   c. minimum pulse width
   d. maximum pulse width

4. In electromagnetic radiation, with a wavefront that is vertically polarized, the E and H fields
   a. are parallel to the earth's surface
   b. are perpendicular, with the H field horizontal to the earth's surface
   c. are perpendicular, with the E field horizontal to the earth's surface
   d. do not determine polarization

5. Ionization of the atmosphere is affected irregularly by
   a. the earth's rotation about its axis
   b. the sun's rotation about its axis
   c. meteorites entering the atmosphere
   d. the height of the F_2 layer

6. The effective height of the ionosphere can be determined by
   a. radiating a signal vertically and determining the lowest frequency that will return to earth
   b. measuring the time it takes a vertically transmitted pulse of energy to return to earth
   c. the maximum distance a signal can be received
   d. the minimum distance a sky wave can be received

7. A radar CRT with a low persistence requires which of the following?
   a. High PRF and high antenna speed
   b. Low PRF and high antenna speed
   c. High PRF and low antenna speed
   d. Low PRF and low antenna speed

8. An antenna's directivity is determined by
   a. the absence of nulls when making a polar plot
   b. the amount of power required for operation
   c. its ability to receive or transmit energy in the desired direction
   d. the polarity of the energy transmitted or received

9. The height of the F_1 and F_2 layers are varied regularly by
   a. sporadic F layers
   b. magnetic storms
   c. seasonal and eleven-year sunspot cycle
   d. solar flares

10. For a given angle of radiation the critical frequency is the
    a. highest frequency that will be refracted from the ionosphere
    b. frequency that will reach a given area
    c. frequency that will completely penetrate the ionosphere
    d. frequency assigned by the FCC

11. For a given antenna dish size, an increase in the operating frequency of the transmitter will result in
    a. lower gain and greater beamwidth
    b. higher gain and less beamwidth
    c. lower gain and less beamwidth
    d. higher gain and greater beamwidth

12. Reflection of electromagnetic radiation is the result of the wave
    a. bouncing off an object with a good reflecting surface
    b. entering the ionosphere and returning to earth
    c. passing through temperature and moisture layers in the atmosphere
    d. being reradiated from a surface larger than one-half wave length of the incident wave

density of the ionosphere changes from
son to season because of
variation in temperature of the earth's
surface
changes in attitude of the earth with
respect to the sun
emperature inversion
he variation of radiation from the sun

t is the reason for using as high a
uency as possible for sky wave trans-
sion?
ess attenuation at higher frequencies
ess interference from noise
ess effect due to changes in ionosphere
the F_2 layer can be used all the time

ch radar antennas normally have
gh vertical gain and low horizontal
in
de vertical beamwidth and narrow
rizontal beamwidth
w vertical gain and low horizontal gain
rrow vertical beamwidth and wide
rizontal beamwidth.

lectromagnetic wave is refracted by
iking a good conducting surface
ing bent as it passes through varying
nsities of atmosphere
ng bent around peaks such as moun-
ns
iking any object one-half wavelength
more in size

ption of RF energy traveling as a
wave will increase
r salt water
vertical polarization
decreased frequency
increased frequency

lous propagation is caused by
spot activity
earth's rotation
rmal atmospheric conditions
luctivity of earth's surface

19. Forward scatter propagation at VHF and UHF ranges has given satisfactory communications up to 1,200 miles at frequencies of
    a. 25 to 60 megacycles, using ionospheric scatter
    b. 100 to 10,000 megacycles, using tropospheric scatter
    c. 25 to 60 megacycles, using tropospheric scatter
    d. 100 to 10,000 megacycles, using ionospheric scatter

20. In propagation by sky wave,
    a. skip zone increases as frequency is decreased
    b. critical angle increases as frequency is decreased
    c. skip distance increases as frequency is decreased
    d. high frequencies will bend in the ionosphere more than low frequencies

21. The location of a VHF antenna should
    a. be high above ground, on a flat site, away from a wooded area
    b. be mounted horizontally for best efficiency
    c. not be mounted near salt water areas
    d. have no effect on transmission and reception

22. Ground-wave propagation is
    a. not affected by conductivity of the earth
    b. normally vertically polarized to eliminate noise
    c. effective for long range communications
    d. normally vertically polarized for minimum loss of transmitted signal

23. The factor that absolutely limits the minimum range of a radar is
    a. pulse width
    b. pulse-repetition frequency
    c. receiver sensitivity
    d. duty cycle

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CHAPTER 7

WAVEGUIDES AND CAVITY RESONATORS

The frequencies employed by microwave equipments, such as radar, make possible the use of two unique, but very practical devices—waveguides and cavity resonators. A WAVEGUIDE is a hollow pipe for transferring high-frequency energy. A CAVITY RESONATOR is a hollow metallic cavity in which electromagnetic oscillation can exist when the cavity is properly excited. The purpose of this chapter is to acquaint you with these devices. It discusses their theory, operation, and uses.

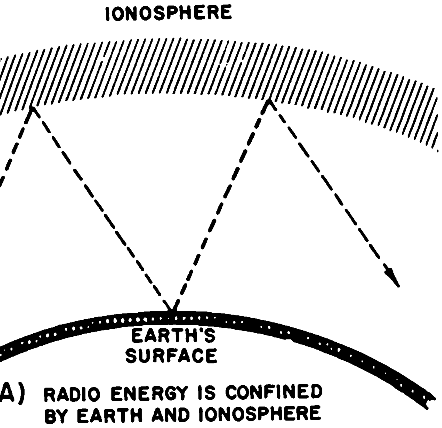
WAVEGUIDES

Guided and Unguided Electromagnetic Waves

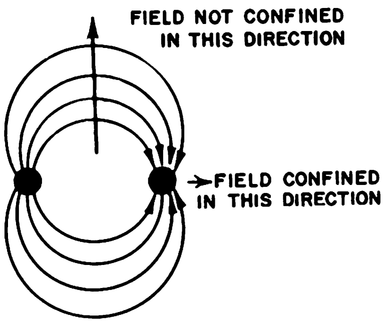
In general, there are two methods for transferring electrical energy: one is by current flow in conductors; the other is by movement of electromagnetic fields in space. Electrical energy can be transferred as current flow in a number of types of transmission lines, for example, two-wire lines and coaxial lines. In space, energy is transferred by moving electromagnetic fields, an example being the radiation of energy from a radio antenna. Many electromagnetic fields which move in space are confined largely to the area between the earth and the ionosphere, as shown in (A) of figure 7-1. (The ionosphere is the thick layer or cloud of free ions and electrons which exists at a height of about 60 miles above the earth.) The change in the dielectric constant of this part of the atmosphere is sufficient to refract electromagnetic fields which strike it. If this refraction is great enough, the fields will be returned to the earth. All electromagnetic fields are not returned, for extremely high-frequency radiations that strike it almost perpendicularly penetrate the ionosphere and are lost. An electromagnetic field that does not start out in a direction parallel to the earth and the ionosphere follows a zigzag path between these two areas and may or may not be reflected back to the earth.

Although the transfer of energy by electromagnetic fields and by currents in conductors may seem to be unrelated phenomena, actually at present, electronics scientists tend to regard even two-wire lines as elements which guide electromagnetic fields from one place to another. The currents in the wires are considered incidental to the action and the result of the moving fields.

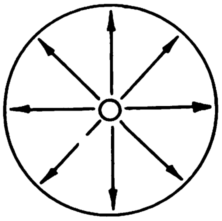
A two-wire line is a poor guide for transferring electromagnetic fields, because it does not confine the fields in a direction perpendicular to the plane which contains the wires. (See (B) of fig. 7-1.) This results in some energy escaping in the form of radiation. Electromagnetic fields may be completely confined in this direction when one conductor is extended around the other to form a coaxial cable, as shown in (C). In a coaxial cable, energy transfer also is said to take place by the motion of electromagnetic fields, rather than by current flow. However, this method is not very efficient at very high radiofrequencies since skin effect limits the current carrying area of a conductor to a thin layer of its surface. Another disadvantage is that the ability of the field to form is limited by the amount of current flow associated with it. When the resistance in a conductor is increased, current flow is reduced accordingly. This reduces the magnitude of the fields. On inspecting the cross section of the coaxial cable, you can see that the surface area of the inner conductor is much less than the surface area of the outer conductor. This causes the inner conductor to retard the current considerably more than the outer conductor and results in a reduction in the efficiency of energy transfer. If you could remove the center conductor and retain the fields, energy might be transferred with less loss.



A) RADIO ENERGY IS CONFINED BY EARTH AND IONOSPHERE


FIELD NOT CONFINED IN THIS DIRECTION
FIELD CONFINED IN THIS DIRECTION

) END VIEW OF TWO WIRE LINE
ELDS CONFINED IN TWO DIRECTIONS BUT NOT IN OTHER TWO.



END VIEW OF COAXIAL CABLE
:LDS CONFINED IN ALL DIRECTIONS

igure 7-1.—Guiding waves.

magnetic fields can transfer energy in
:h does not have a center conductor
he configuration of the fields is
compensate for the missing con-
: object remaining, which is virtually
e, is called a WAVEGUIDE. A wave-
not necessarily have to be circular
section. Practical waveguides, for
ıre usually rectangular in cross

Metallic walls are not necessary to guide electromagnetic fields in a waveguide, for the fields will be reflected whenever they encounter any kind of a substance which has a different dielectric constant from the substance in which they are traveling. For example, fields can be made to travel through a ceramic rod although with some loss of energy. When they encounter the air at the surface of the rod, they are reflected back into the rod.

Waveguides Vs. RF Lines

As you previously learned, the three types of losses in RF lines are copper losses, dielectric losses, and radiation losses. Briefly these losses are described as follows: Copper loss is an I_2R loss. It becomes appreciable whenever skin effect reduces the conducting area of the lines. Dielectric losses, as you recall, are losses due to the heating of the insulation between conductors. Radiation losses are losses due to energy escaping from RF lines in the form of radiation.

ADVANTAGES OF WAVEGUIDES

Considering waveguides from the point of view of these losses, they have the following advantages:

1. Copper losses are small in waveguides. Since a two-wire line consists of a pair of conductors which are small, the surface area of each is likewise small. Although the surface area of the outer conductor of a coaxial cable is large, the inner conductor is small and produces considerable copper losses. On the other hand, a waveguide does not depend on conduction through a center conductor. Therefore, whenever current flows, this flow is in the walls, and copper losses are less than those in other types of lines.

2. Dielectric losses are small in waveguides. In two conductor lines, some form of insulation is used between the conductors. The fields which move around this insulator cause heat, and the heat in turn takes power from the line. A waveguide has no center conductor to support. Furthermore, there is only air in the hollow pipes. Since the dielectric loss of air is negligible, it follows that the dielectric losses in a waveguide are small.

3. Radiation losses are less in a waveguide than in a two-wire line. In a waveguide, fields

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are contained wholly within the guide itself, just as in a coaxial line. Therefore, only a negligible amount of energy is radiated.

4. The power-handling capacity of a waveguide is greater than that of a coaxial line having an equal size. Power function of E_2/Z_o, where E is the maximum voltage in the traveling wave and Z_o is the characteristic impedance of the line. E is limited by the distance between the conductors. In the coaxial line (fig. 7-2), this distance is S_1. In the waveguide, the distance which is S_2 is much greater than S_1. Therefore, the waveguide is able to handle greater power before the voltage exceeds the breakdown potential of the insulation.

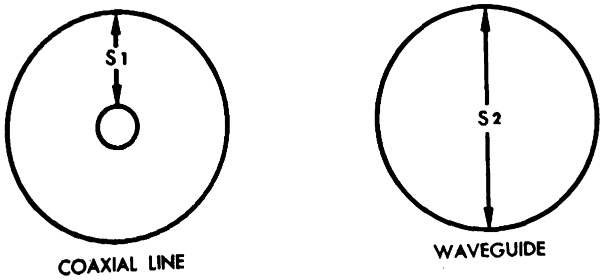


Figure 7-2.—Comparison of spacing in coaxial line and waveguide.

5. A waveguide is simpler to construct than a coaxial line, since the center conductor is eliminated completely.

6. The physical stamina of a waveguide is greater than that of a coaxial line. Unlike a coaxial line, it has no center conductor or insulators which can be displaced or broken.

DISADVANTAGES OF WAVEGUIDES

In view of the advantages, you may wonder why waveguides are not used exclusively for transferring energy. There is, however, one major disadvantage which makes waveguides impractical at any but extremely high frequencies. The cross-sectional dimensions of a waveguide must be in the order of a half wavelength for it to contain electromagnetic fields properly. A waveguide used at one megacycle, for example, would be about 700 feet wide. At 200 mc. this waveguide would have to be about 4 feet wide, while at higher frequencies, such as 10,000 mc., it need be only one inch wide. Therefore, dimensions which waveguides require make them impractical at any frequency lower than about 3,000 mc. If the critical dimension of the guide is less than a half wavelength, energy will not be propagated through the waveguide. The reason for this is that for any given waveguide there is a cutoff frequency, below which it does not function as a power transfer device. This also limits the frequency range of any system using waveguides. Coaxial cables do not have this limitation for they have no cutoff frequency and will transmit low as well as high frequencies.

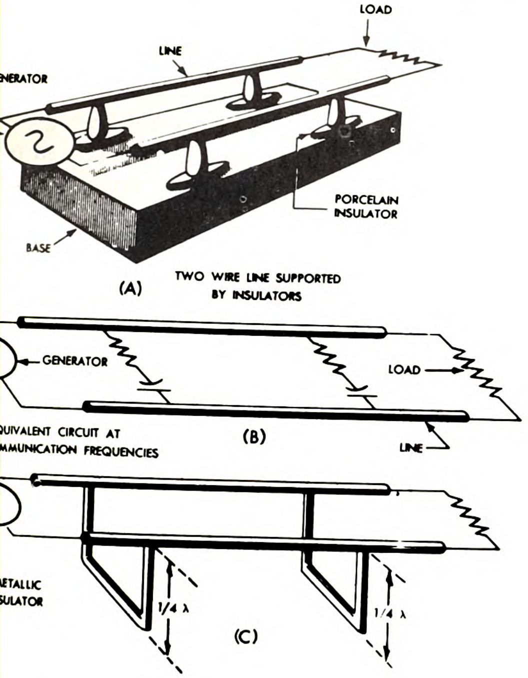
The installation and operation of waveguide transmission systems are somewhat more difficult than for other types of line. The radius of bends in the line must be greater than two wavelengths to avoid excessive attenuation. This fact may hamper installations in restricted spaces. If the guide is dented, or if solder is permitted to run inside the pipe when joints are made, the attenuation of the lines is greatly increased. In addition to the increased attenuation that they cause, dents or beads of solder also reduce the breakdown voltage of the waveguide. Although such faults may not cause actual arc-over in the guide, they limit the power-handling capacity of the system and make the possibility of arc-over more likely. Thus, unless great care is exercised in the installation, one or two carelessly made joints may completely nullify the initial advantage obtained from the use of the waveguide.

WAVEGUIDE THEORY

An exact mathematical analysis of the way in which fields exist in a waveguide is quite complicated. However, it is possible to obtain an understanding of many of the properties of waveguide propagation by using the following simple analogy, which shows how the fields are able to exist in a waveguide and how they can be handled.

Analogy of Waveguide Action From a Two-Wire RF Line

To understand the action of a waveguide, assume that it has the form of a two-wire line. In this condition there must be some means of supporting the two wires. Furthermore, the support must be a nonconductor, so that no power will be lost by leakage resistance. An efficient way for insulating and supporting the two-wire line is shown in figure 7-3 (A). This



gure 7-3.—Insulating the two-wire line.

s spaced, insulated, and supported by
ain standoff insulators. At radiofrequen-
the absorption of power by the dielectric
ial (insulators) causes them to appear as
istance and capacitance. The equivalent
cal circuit at radiofrequencies is shown
of the figure. For frequencies of 3,000
nd above a better insulator than non-
ting porcelain must be used. A superior
equency insulator for this purpose is a
-wave section of RF line called a metallic
or. (See fig. 7-3 (C).) Since there are no
ric losses in a quarter-wave section of
line, the impedance at the open end
n of the two-wire line) is very high.
etallic insulator can be placed anywhere
two-wire line. Several insulators on
de of a two-wire line are shown in figure
. A point to note in this line is that the
s are a quarter-wave at only one fre-
This limits the high efficiency of the
e line to only one frequency.

use of several insulators results in
d conductivity of a two-wire line when the
are connected together. This connection
between the two adjacent insulators
a switch, as illustrated in figure 7-4
en the switch is open, both quarter-
ctions are excited by the main line. In this condition, there will be standing waves on the quarter-wave sections. When the switch is connected to the same place on each section, the relative phase relationship of the voltages at the connection will be the same for each section. In this condition, the No. 1 section will be excited first by the generator. When the switch is closed, the No. 2 section will be partly excited by the No. 1 section through the switch connection. In this condition, less energy from the main line will be required to excite the No. 2 section. The parallel paths shown cause less resistance to exist along a given length of line, and energy is transferred with less copper loss.

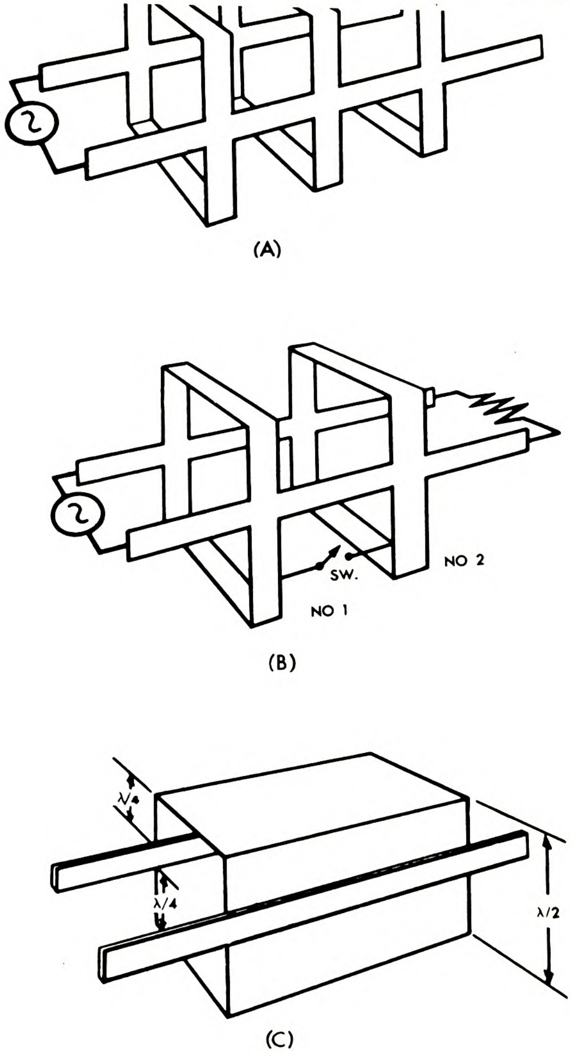


Figure 7-4.—Development of waveguide by adding quarter-wave sections.

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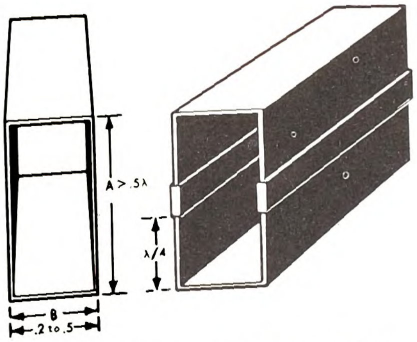
When additional sections are added to the line until each section makes contact with the next, the result is a rectangular box in which the line is at the center, as shown in figure 7-4 (C). The line itself is actually part of the wall of the box. The rectangular box thus formed is a waveguide.

EFFECT OF DIFFERENT FREQUENCIES ON A WAVEGUIDE

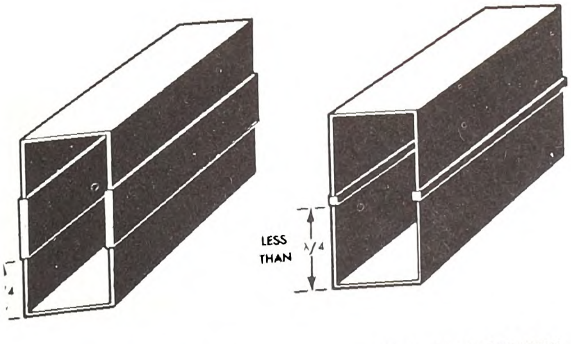
Previously it was stated that a quarter-wave section is limited in operation to a certain frequency. However, when a solid wall of insulators is added, the section will operate at other frequencies. The waveguide shown in figure 7-5 (A) is the one just discussed. When the frequency being transferred by the guide is made higher, the quarter-wave section must be shorter. These shorter wavelengths are easily accommodated if you assume that this two-wire line is made up of a wide bar or strip in each wall of the guide, as shown in (B). The shorter distance remaining is the shorter quarter-wave section. Thus, the wide bar shown is theoretically well insulated at any frequency higher than the near-minimum frequency illustrated in (A). In reality, there is a practical upper frequency limit to which this analogy is applicable. For example, when the bar is a half wavelength across, the waveguide will be four quarter wavelengths across and may act as though there were two bars instead of one.



WAVEGUIDE DIMENSIONS

NEAR MINIMUM FREQUENCY

(A)



ABOVE MINIMUM FREQUENCY

(B)

BELOW MINIMUM FREQUENCY

(C)

Figure 7-5.—Effect of different frequencies in the waveguide.

The next consideration is a frequency which is lower than the original frequency. Lowering the frequency in a given waveguide will lengthen the sections and narrow the bar. Below a certain frequency this bar does not exist because the quarter-wave sections meet one another. At a still lower frequency, the sections become less than a quarter-wave. (See fig. 7-5 (C).) A shorted section less than a quarterwave is inductive. Thus, the impedance across the place where the conducting bars belong is NOT a high resistance but an inductance. The inductive reactance will dissipate the energy swiftly through high currents which flow back and forth in the line as though the inductance were taking energy during one half cycle and then returning it to the line during the next half cycle. Thus it follows that in a waveguide there is a low-frequency limit or cutoff frequency, below which the waveguide cannot transfer energy. The width of the waveguide at the cutoff frequency is equal to one half wavelength, since at this frequency the two quarter-wave sections touch and add to one another. Mathematically, the cutoff wavelength is expressed by the equation,

$$\lambda_c = 2A$$

where λ_c is the cutoff wavelength, and A is the wide dimension of the rectangular cross section.

Cutoff occurs when the width of a waveguide is below a half wavelength. Most waveguides are then made 0.7 wavelength in the wide dimension to give a margin between the actual size and the size for cutoff. The other dimension is the distance between conductors, and similarly, as in the two-wire lines, is governed by the voltage breakdown potential of the dielectric (usually air), and other factors. Widths of 0.2 to 0.5 wavelengths are common.

Electromagnetic Fields in a Waveguide

An understanding of the fields present in a vaveguide is necessary in order for the guides o be used effectively. Energy in a waveguide is ransferred by the electromagnetic fields, while urrents and voltages merely aid in forming hese fields. It is important to know when a ood current path is required and where the oltage will be high. Also it is important to now where the fields will exist since it is by ieans of these fields that energy is normally itroduced into or removed from the guides. he operation of a waveguide involves two kinds fields—the electrostatic and the electro- agnetic.

HE ELECTRIC FIELD

The existence of an electrostatic (electric ld) indicates that there is a difference in the mber of electrons between two points. The nplest form of electrostatic field is the one ich occurs between the two parallel plates of capacitor. (See fig. 7-6 (A).) When the top te of the capacitor is made positive by a tery, electrons move from the top plate and osit themselves on the bottom plate. This mediately sets up a stress in the dielectric ween the plates. This stress is represented arrows, whose direction is from the more itive voltage point to the less positive, or ative, voltage point. The amount of stress is cated by either the length or the number of ows. A long arrow represents more stress a short arrow. In representing electrostatic ds, the NUMBER of arrows indicates the ngth of the field (fig. 7-6). In the case of capacitor, note that the arrows are evenly ed across the area between the two plates. he voltage across the plates is the same at points, the electrostatic lines between the s are evenly distributed. This set of lines s an electrostatic field. This field is usually d the ELECTRIC FIELD and is abbreviated E-FIELD. The lines of stress are called -LINES.

otice in (B) of figure 7-6 that the two-wire mission line has an instantaneous standing of voltage applied to it. This line is equal e wavelength. At the same time, part of it sitive, while another part is negative. The taneous electrostatic field (E-field) is the at the negative and positive points, but the

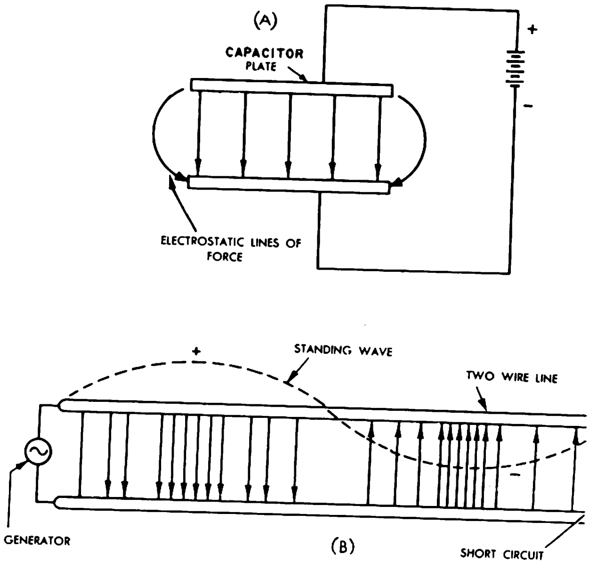


Figure 7-6.—Electric field between capacitor plates and a full-wave section of two-wire line.

arrows representing each field point in opposite directions. The voltage along the line varies sinusoidally. Therefore, the density of the E-lines varies sinusoidally.

An easy way to show the development of the E-field in a waveguide is from a two-wire line which has quarter-wave insulators. Figure 7-7 shows the two-wire line previously discussed with several double quarter-wave insulators, or half-wave frames used as insulators.

The E-field on the main line is the same as that in the transmission line, as illustrated in figure 7-6. The half-wave frames located at points of high voltage (strong E-field) will have a strong E-field across them. The half-wave frames located at a voltage minimum point will have no E-field across them. Frame (A) of figure 7-7 is an example of an insulator which has a strong E-field across it. Each frame is shown separately below the main line for a clearer view. Frame (B) is at zero voltage point, so it will have no field on it. Frame (C) also has a strong field, but its polarity is reversed. Frame (D) has a weaker field on it due to its being at a lower voltage point on the main line. The picture shown is a buildup to the three dimensional aspect of the full E-field in a waveguide.

Figure 7-8 shows the E-field in an actual waveguide. This is the field which results when

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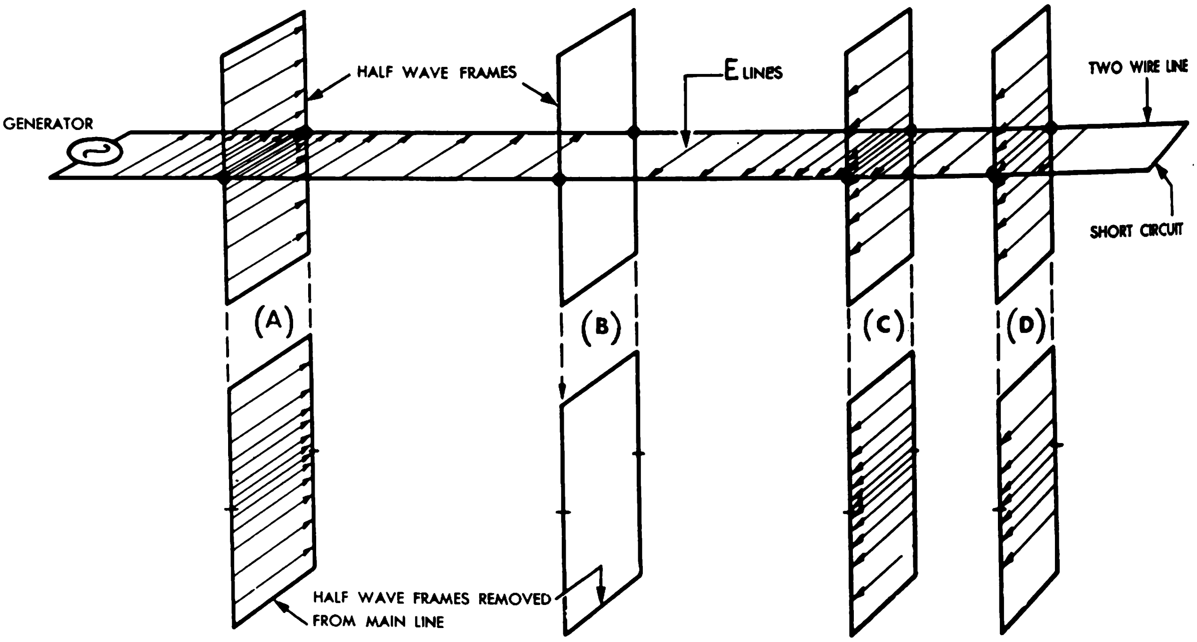

Figure 7-7.—Magnitude of fields on half-wave frames vary with strength of field on main line.

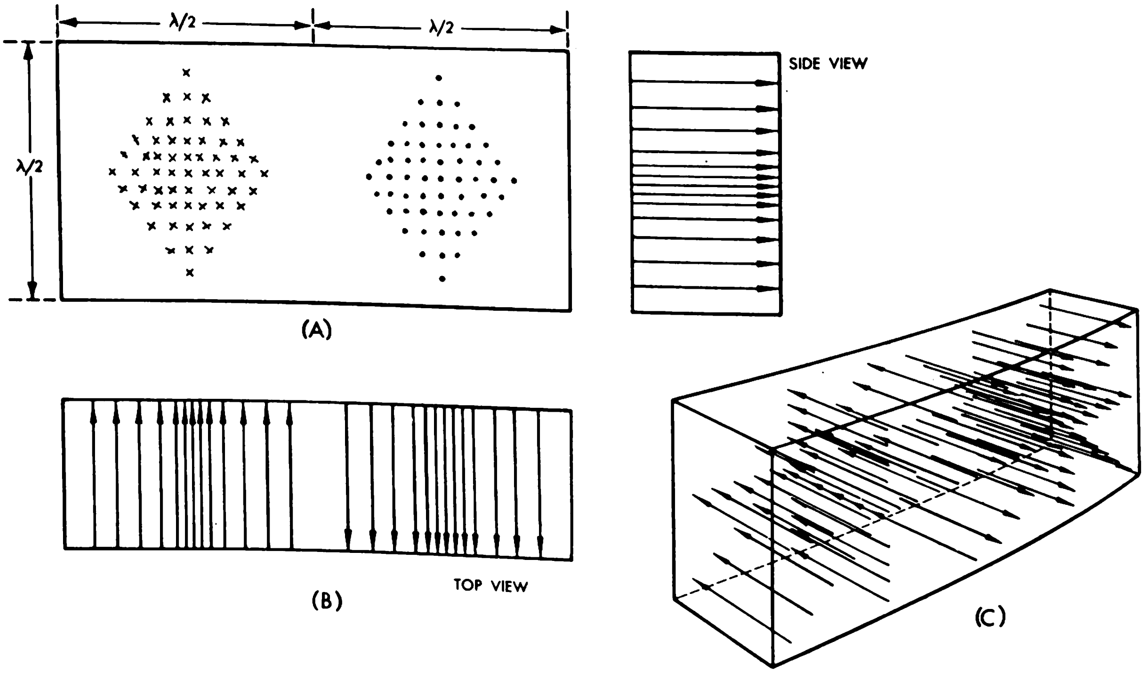

Figure 7-8.—E-field on an actual waveguide.

inite number of quarter-wave sections are eted to the line to form a rectangular The E-field is strong at one-quarter and quarter distances from the shorted end, comes weaker at the sine rate toward the and lower walls and toward the ends and . Again the phenomenon of wavelength is t, as shown in (A). You should realize, of , that this is an instantaneous picture at the time the standing wave of voltage ts peak. At other times, the voltage and vary from zero to the peak value, re- direction every alternation of the ap- oltage.

tain boundary conditions must exist in for propagation to occur in a waveguide. incipal one is that there must be no field tangent to the walls of the guide. satisfied by the E-field diminishing to the top and bottom of the guide by natural action; while at other places, the field endicular to the walls.

conductor. The presence of the force is shown by closed loops around the single wire in (A) of figure 7-9. The closed loops are formed of magnetic lines of force, or H-lines, which must be continuous, or closed, in order to exist. These lines are associated with a current; their number varies directly with the amount of current present; and the total number of lines considered collectively is called the H-FIELD. Each H-line has a definite direction, which can be determined by use of the left-hand rule; and in the diagrams which follow, the strength of the field is indicated by the number of H-lines drawn in a given area.

Although H-lines encircle a single straight wire, they behave differently when the wire is wound into a coil. (See fig. 7-9 (B).) In a coil the individual H-lines tend to form around each turn of wire, but in doing so take opposite directions between adjacent turns. This causes cancellation and results in zero field strength between the turns. But inside and outside the

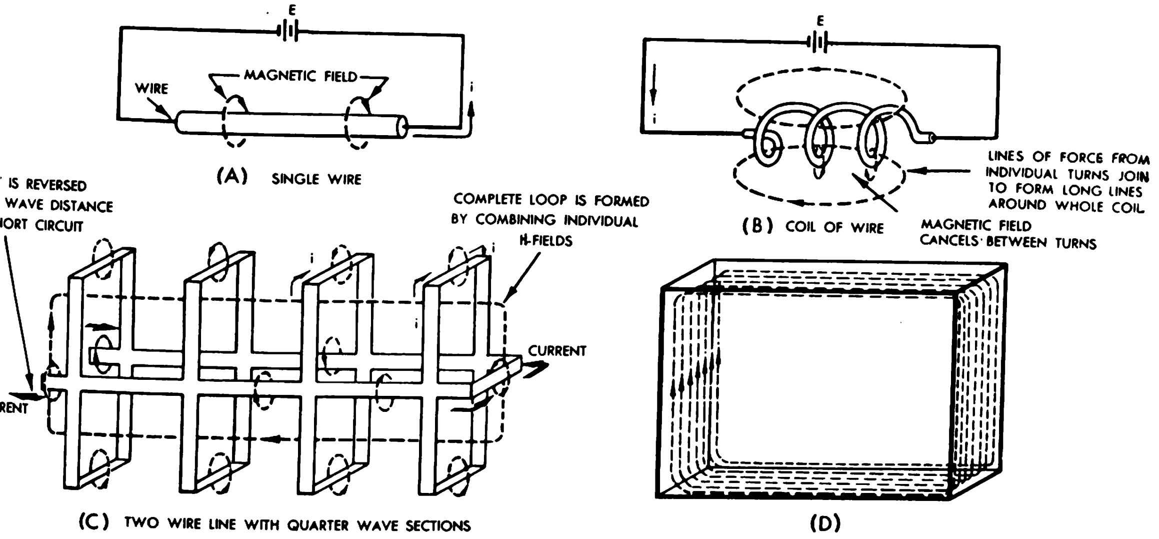
E
WIRE
MAGNETIC FIELD
i
(A) SINGLE WIRE
E
i
LINES OF FORCE FROM INDIVIDUAL TURNS JOIN TO FORM LONG LINES AROUND WHOLE COIL
(B) COIL OF WIRE
MAGNETIC FIELD CANCELS BETWEEN TURNS
IS REVERSED WAVE DISTANCE ORT CIRCUIT
COMPLETE LOOP IS FORMED BY COMBINING INDIVIDUAL H-FIELDS
i
CURRENT
RENT
(C) TWO WIRE LINE WITH QUARTER WAVE SECTIONS
(D)

Figure 7-9.—Development of magnetic field or H-field in the waveguide.

GNETIC FIELD

econd field which must always exist in de is the magnetic field. The magnetic orce which make up the magnetic field ed by the MOVEMENT of electrons in cting material. All the tiny magnetic erted by the individual moving electrons her and form a large force around the

coil, the directions are the same for each H-field. Therefore, the fields join and form a continuous H-line around the entire coil.

Similar action also takes place in a waveguide. In diagram (C) of figure 7-9, a two-wire line with quarter-wave sections is shown. Currents flow in the main line and in the quarter-wave sections. The current direction produces the individual H-lines around each conductor

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When a large number of sections exist, the field cancels between the sections but their directions are the same inside and outside the waveguide. At half-wave intervals on the main line, current will flow in opposite directions. This produces H-line loops having opposite directions. In (C), current at the left end is opposite to the current on the right end. The individual loops on the main line are opposite in direction. All around the framework, they join in such a manner that the long loops shown in (D) are formed. Outside of the waveguide, the individual loops cannot join to form a continuous loop. Thus, there is no magnetic field outside of a waveguide.

Figure 7-10 shows a conventional presentation of the magnetic field in a waveguide three half wavelengths long. Note that the field is strongest at the edges of the waveguide. This is where the current is the highest. The current is lowest at the center of each set of loops because there the standing wave of current is zero at all times. The picture shown represents an instantaneous condition. During the peak of the other half cycle of a-c input, all field directions are reversed. An instantaneous picture of this condition would show the fields reversed at half-wave intervals, since the current in the long line is reversed over half-wave distances.

A second boundary condition necessary for electromagnetic fields to transfer power is satisfied by the configuration of the magnetic field. This condition requires that at the surface of the waveguide there be no perpendicular component of the magnetic field. Since all the H-lines are parallel to the surface, this condition is satisfied. Thus, energy can be transmitted by a waveguide and will be carried in the electromagnetic fields within the guide. Since the electric field is zero wherever it is parallel to the metal surface of the guide, no part of this field can penetrate the metal. In the same way, the varying magnetic field is zero at the surface of the metal wherever it attempts to penetrate the walls of the guide, so that no part of the magnetic field can get outside the guide. Therefore, all of the energy in the field is wholly contained by the guide. Thus, measurements on the outside of the guide can detect neither oscillating electrons nor any electromagnetic fields caused by the electrical energy within the waveguide.

Electric and magnetic fields exist simultaneously in the waveguide. In fact, the H-field causes a current which in turn causes a voltage difference. This causes an E-field and it in turn causes a current which causes an H-field. This is a continuous action. One field is dependent on the other as energy is continually transferred from one field to the other.

The conventional picture of both fields in the waveguide is shown in (A) of figure 7-11. Since this picture is rather complicated, the presence and direction of the field is usually indicated in simpler diagrams, such as (B) and (C). In these diagrams the number of E-lines in a given area indicates the strength of the electrostatic field, while the number of H-lines in any given cross section indicates the strength of the magnetic field in that area.

The field configuration shown in this illustration represents only one of the many ways in which fields are able to exist in a waveguide. Such a field configuration is called a MODE of operation. In the case of the rectangular waveguide illustrated in figure 7-11 the configuration

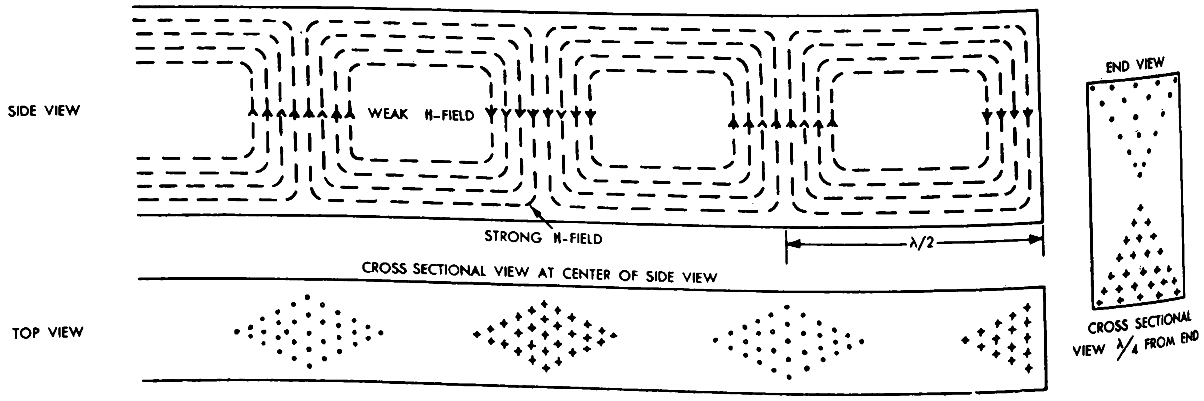
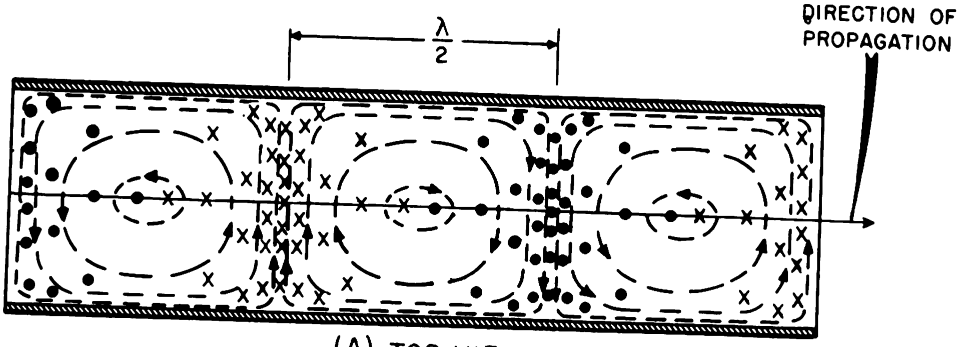
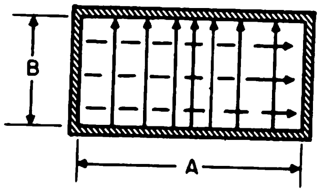

SIDE VIEW
WEAK H-FIELD
STRONG H-FIELD
λ/2
CROSS SECTIONAL VIEW AT CENTER OF SIDE VIEW
TOP VIEW
END VIEW
CROSS SECTIONAL VIEW λ/4 FROM END

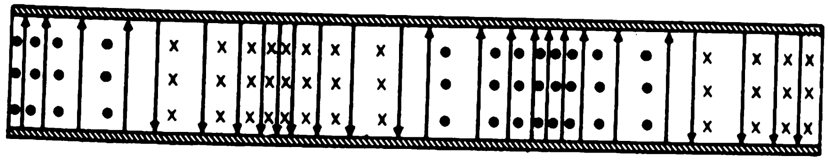
Figure 7-10.—Magnetic field in waveguide three half wavelengths long.



(A) TOP VIEW



(B) END VIEW



(C) SIDE VIEW

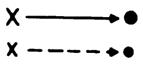


Figure 7-11.—Conventional picture of both fields in a waveguide.

nown as the DOMINANT mode, since it has lowest cutoff frequency.

Other higher modes—that is, different field igurations—may occur accidentally or may aused deliberately in a waveguide.

n example of another field configuration is loped in (A) of figure 7-12. If the size of waveguide is doubled over that of the wave- e shown in the previous illustration, the s section will be a full wave rather than a wave. The two-wire conductor can be as- ed to be a quarter wave down from the top a quarter wave up from the bottom). The ining distance to the bottom is three- ers of a wave. A three-quarter wave on has the same high impedance input as the quarter-wave section. Thus the two-wire line is properly insulated and will transfer energy. The field configuration will show a full wave across the wide dimension, as you can see in (B).

A rectangular field configuration can be applied to a circular waveguide. The two conductors shown in (C) of figure 7-12 are assumed to be part of the waveguide wall. The remaining part of the wall forms the quarter-wave sections each of which acts as an insulator between the two conductors. This makes it possible to transfer energy with minimum losses. The resulting field configuration, shown at (D), is the dominant mode for a waveguide with a circular cross section.

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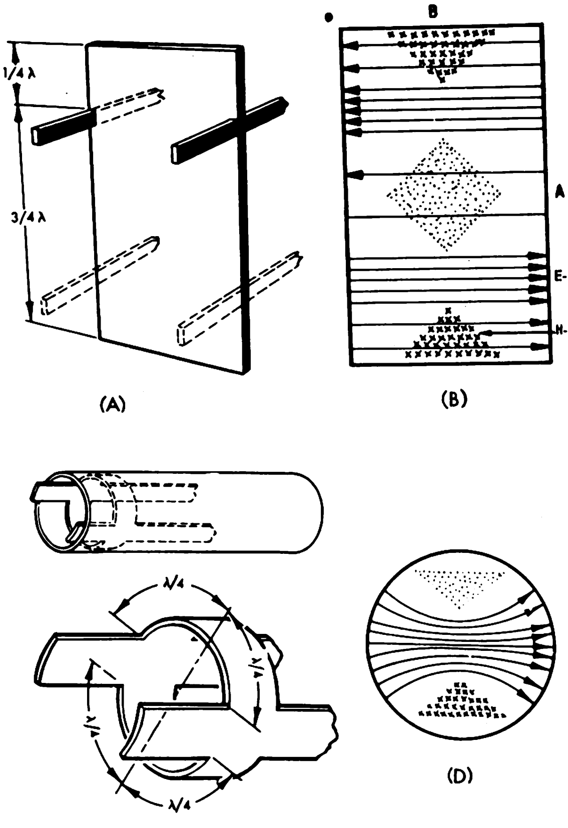

(A) (B)

(C) (D)

Figure 7-12.—Other field configurations in waveguides.

NOTE: The cutoff wavelength of circular waveguide for the dominant mode is 1.71 times the diameter of the guide. Thus the diameter must be 2/1.71 or 1.17 times the A dimension (wide dimension) of a rectangular guide having the same cutoff frequency.

Analogy of Waveguide Action by Electric Waves

A somewhat different analogy involving waveguide action deals with the field rather than with current and voltages. This analogy is somewhat more exact than the previous explanation which dealt with voltages and current in two-wire lines, for power flow in this case is assumed to be in the fields rather than in the conductors.

In a waveguide the fields are the same as those radiated into space by an antenna. Figure 7-13 shows a small portion of such a field which is radiated into space from an antenna. In it the electrostatic lines of force, or E-lines, are parallel to the antenna, and the electromagnetic lines of force or H-lines are perpendicular to the antenna. They move away from the antenna at the speed of light. At each half cycle the polarity is reversed. Therefore, at half-wave intervals, the fields are in opposite direction (or polarity). Although only a small part of the total field is shown, actually the E-lines and H-lines form huge closed loops after they leave the antenna.

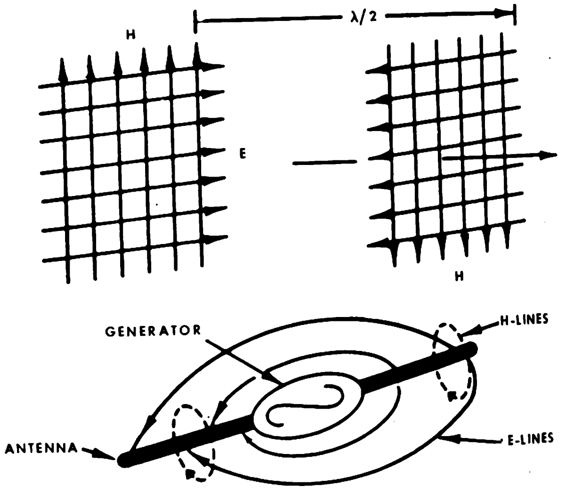

Figure 7-13.—Small portion of field radiated into space by an antenna.

As previously mentioned, the energy which moves through a waveguide and the energy which is radiated by an antenna are both the same form of electromagnetic radiation. Nevertheless, the field configuration shown in figure 7-11

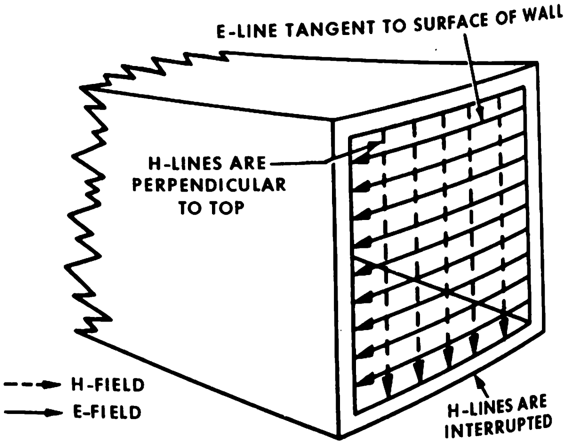
E-LINE TANGENT TO SURFACE OF WALL
H-LINES ARE PERPENDICULAR TO TOP
H-FIELD
E-FIELD
H-LINES ARE INTERRUPTED

Figure 7-14.—Fields in a waveguide must satisfy boundary conditions to be radiated.

cannot exist in a waveguide because it does not satisfy the required boundary conditions. First, there cannot be any E-lines tangent to the surface of the walls. Since the E-lines are evenly distributed across the area, some will be across the top and bottom walls. This causes the voltage to short out, and, in turn, the E-lines vanish. Other E-lines which are pushed up to the wall by the repulsion between E-lines likewise short out. This shorting out is cumulative and eventually removes the entire E-field.

The second boundary condition which must be satisfied is that there must be no component of the magnetic field perpendicular to the wall. Note again in the illustration that the H-lines are parallel to the side walls which is correct—but are perpendicular to the bottom, which cannot be; so H-lines of this type cannot exist in the waveguide either. Furthermore, an H-line cannot exist unless it is a closed loop.

When a small antenna is placed in the waveguide and excited at an RF frequency, both ositive and negative half cycles are radiated. See fig. 7-15.) The wavefront produced is like n expanding circle. The part which travels in he direction of arrow B goes straight down the aveguide and is quickly attenuated, as preiously described. However, the part of the avefront which travels in the direction of rrow A is reflected from the wall. The wall is short circuit and causes the wavefront to be eflected in reverse phase. Meanwhile, the waveont which travels in a direction C is reflected om the other wall and proceeds in opposite ase. Thus, the radiation fields are contained the waveguide.

PATH OF WAVEFRONTS IN A WAVEGUIDE

In the side view of the waveguide, figure 7-16 (A), the light solid and light broken lines represent the wavefront going in direction A. The heavy solid and heavy broken lines represent the wavefront going in direction B. Note that all parts of the wavefront A are traveling upward at an angle across the guide. Wavefront B is traveling at the same angle but downward.

When the wave travels in this fashion in a waveguide, propagation is possible. In understanding what happens, note that the positive wavefront (represented by both light and heavy SOLID lines) occurs simultaneously throughout the center of the guide. These fronts add and cause a maximum voltage to occur at the center. The E-field is shown maximum at the center in diagram (B) of figure 7-16. The negative wavefront (represented by both light and heavy BROKEN lines) adds in the same manner as the positive wavefront. When the negative wavefront meets the positive wavefront at the walls, the two wavefronts cancel each other, making the total voltage equal to zero. This verifies the E-field condition shown in (B). With the E-field zero at the edges, it is possible for the E-field to exist in the waveguide.

CROSSING ANGLE

The angle at which a wavefront crosses a waveguide is a function of the wavelength and the cross-sectional dimension of the waveguide. At some intermediate frequency the reflection

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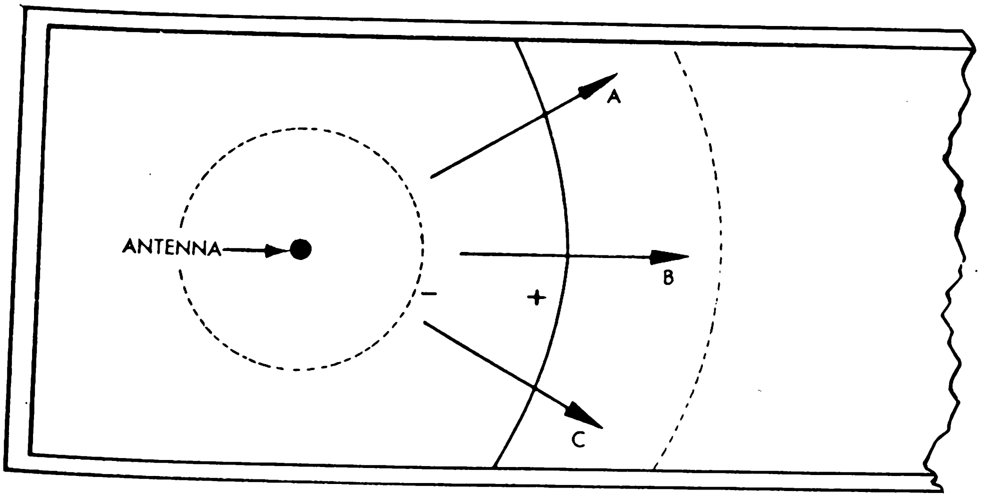
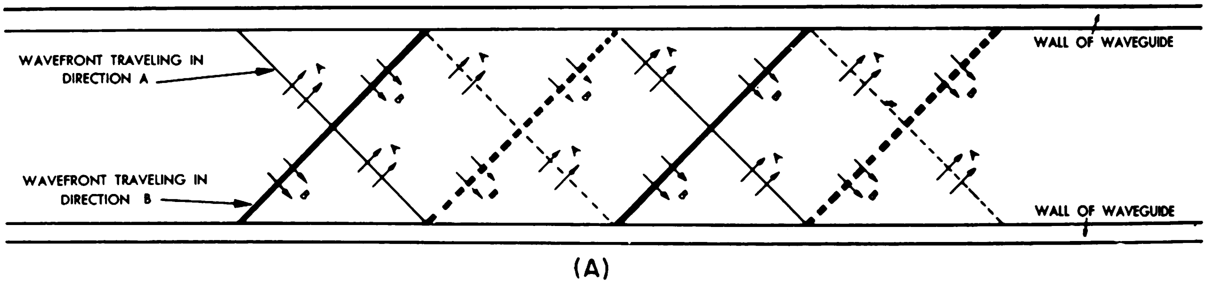


Figure 7-15.—How radiation fields are made to fit a hollow pipe.


WAVEFRONT TRAVELING IN DIRECTION A
WAVEFRONT TRAVELING IN DIRECTION B
WALL OF WAVEGUIDE
WALL OF WAVEGUIDE
(A)

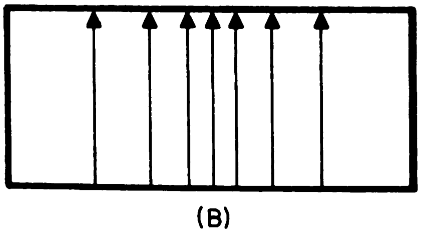


Figure 7-16.—Paths of wavefronts in waveguide.

is shown in (B) of figure 7-17. But as the frequency increases, the angle of incidence becomes less and the signal travels farther before it reaches the other side as shown in (A). At lower frequencies, the wavefront crosses the guide at nearly right angles to the walls. At some frequency, the angle will be 90 degrees. At this point, the wave travels back and forth across the guide until the energy is dissipated by the resistance of the walls of the guide. At this frequency, the distance from side to side is one-half wavelength for the waveguide. At the cutoff frequency, the attenuation is a linear function of length and is very high.

The velocity of propagation of a wave along a two-wire line is less than its velocity in air. The same is true in a waveguide. Movement of a wave along a two-wire line is slower than its movement in air because of the retarding effect of the d-c resistance, the conductors, and conductance of the insulation. In the waveguide, the lower velocity is due to the way the field travels. As shown in (C) of figure 7-17, the path of a wavefront at a relatively low frequency is along the zigzag arrow at the velocity of light. But due to the long path, the wavefront actually travels very slowly along the waveguide. In figure 7-17 (A), the frequency is higher, and the wavefront or the group of waves actually travel a given distance in less time than those in (C).

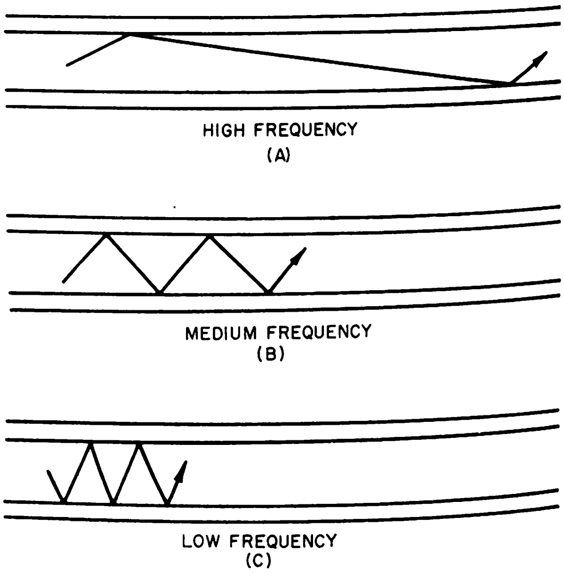
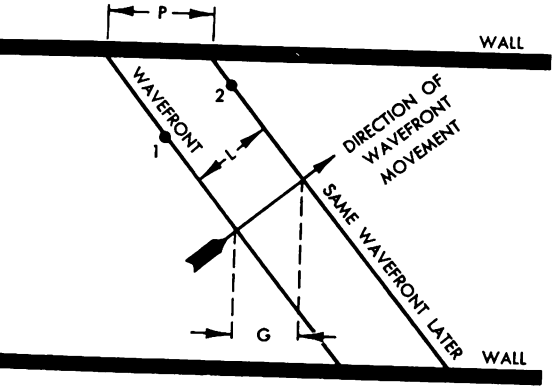


Figure 7-17.—Angle at which fields cross waveguide varies with frequency.

The axial velocity of a wavefront or a group of waves is called the GROUP VELOCITY. The relationship of the group velocity to diagonal velocity causes an unusual phenomenon. The velocity of propagation appears to be greater than the speed of light. As you can see in figure 7-18, during a given time a wavefront will move



gure 7-18.—Relation of phase, group, and wavefront velocity.

ı point 1 to point 2, or a distance L at the city of light (V_L). Due to this diagonal ement (direction of the arrow), the wave- t during this time has actually moved down guide only the distance G, which is nec- rily a lower velocity. This is called group ity (V_g). But if an instrument were used etect the two positions at the wall, they l be the distance P apart. This is greater the distance L or G. The movement of the ct point between the wave and the wall is greater velocity. Since the phase of the RF hanged over the distance P, this velocity lled the phase velocity (V_p). The mathe- al relationship between the three velocities ted by the equation

$$V_L = \sqrt{V_p V_g}$$

velocity of light = 3 x 10^8 meters/second

hase velocity

roup velocity

s equation indicates that it is possible for se velocity to be greater than the velocity t. As the frequency decreases, the angle sing is nearer a right angle. In this con- he phase velocity increases. For meas- tanding waves in a waveguide, it is the velocity which determines the distance ı voltage maximum and minimum. For ason, the wavelength measured in the vill actually be greater than the wavelength in free space. From a practical standpoint, the different velocities are related in the following manner: if the RF frequency being propogated is sine-wave modulated, the modulation envelope will move forward through the waveguide at the group velocity, while the individual cycles of RF energy will move forward through the modulation envelope at the phase velocity. If the modulation is a square wave, as in radar transmissions, again the square wave will travel at group velocity, while the RF waveshape will move forward within the envelope. Since the standing wave measuring equipment is affected by each RF cycle, the wavelength will be governed by the rapid movement of the changes in the RF voltage. Since intelligence is conveyed by the modulation, the transfer of intelligence through the waveguide will be slower than the speed of light, as is the case in other types of RF lines.

Because of the way the fields are assumed to move across the waveguide, it is possible to establish a number of trigonometric relationships between certain factors. As shown in figure 7-19, the angle that the wavefront makes with the wall (angle Θ) is related to the wavelength and dimension of the guide and is equal to

$$\cos \Theta = \frac{\lambda}{2A}$$

where λ is the wavelength in free space of the signal in the guide, and A is the inside wide dimension of the guide. The group velocity (V_g) is related to the velocity of light (V_L) as follows:

$$\frac{V_g}{V_L} = \sin \theta = \sqrt{1 - \frac{(\lambda)^2}{(2A)^2}}$$

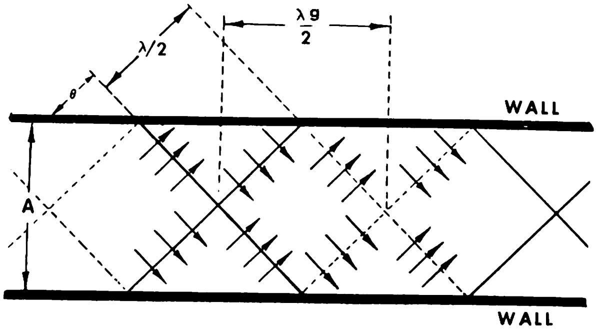


Figure 7-19.—Trigonometric relations exist between factors indicated.

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Further, since it is possible to measure the wavelength in the guide (λ_g), the wavelength in space is equal to

$$\frac{\lambda_g}{\lambda} = \frac{1}{\sin\theta} = \frac{1}{\sqrt{1 - \frac{(\lambda)^2}{(2A)^2}}}$$

Solving for λ, the equation becomes equal to

$$\lambda = \frac{2A\lambda_g}{\sqrt{\lambda_g^2 + 4A^2}}$$

After measuring the wavelength and the inside dimension of the waveguide, it is possible to calculate most other quantities associated with the waveguide.

NUMBERING SYSTEM OF THE MODES

The normal configuration of the electromagnetic field within a waveguide is called the DOMINANT mode of operation. The mode developed for the rectangular waveguide, as was explained before and illustrated in figure 7-10, is the dominant mode of operation. The dominant mode for the circular waveguide was also shown in figure 7-12 (D). A wide variety of higher modes are possible in either type of waveguide. The higher modes in the rectangular waveguides are seldom used in radar, but some of the higher modes in the circular waveguide are useful.

For case in identifying modes, any field configuration can be classified as either a TRANSVERSE ELECTRIC MODE or a TRANSVERSE MAGNETIC MODE. These modes are abbreviated TE or TM respectively. In a transverse electric mode, all parts of the electric field are perpendicular to the length of the guide and no E-line is parallel to the direction of propagation. The TE mode is sometimes called the H-mode. In a transverse magnetic mode, the plane of the H-field is perpendicular to the length of the waveguide. No H-line is parallel to the direction of propagation. This mode is sometimes called an E-mode.

It is interesting to note from these definitions that the wavefront in free space or in a coaxial line is a TEM mode, since both fields are perpendicular to the direction of propagation. This mode cannot exist in a waveguide.

In addition to the letters TE or TM, subscript numbers are used to complete the description of the field pattern. In describing field configurations in rectangular guides, the first small number indicates the number of half-wave patterns of the transverse lines which exist along the long dimension of the guide through the center of the cross section. The second small number indicates the number of transverse half-wave patterns that exist along the short dimension of the guide through the center of the cross section. For circular waveguides the first number indicates the number of full waves of the transverse field encountered around the circumference of the guide. The second number indicates the number of half-wave patterns that exist across the diameter.

COUNTING WAVELENGTHS FOR MEASURING MODES

In the rectangular mode shown in figure 7-20 (A), note that all the electric lines are perpendicular to the direction of movement. This makes it a TE mode. Across the guide along the wide dimension, the E-field varies from zero at the top, through maximum at the center, to zero on the bottom. Since this is one-half wave, the first subscript is one. In the direction across the narrow dimension of the guide parallel to the E-line, the intensity change is zero. Thus, the complete description of this mode is $TE_{1,0}$.

In the circular waveguide in (B), the E-field is transverse and the letters which describe it

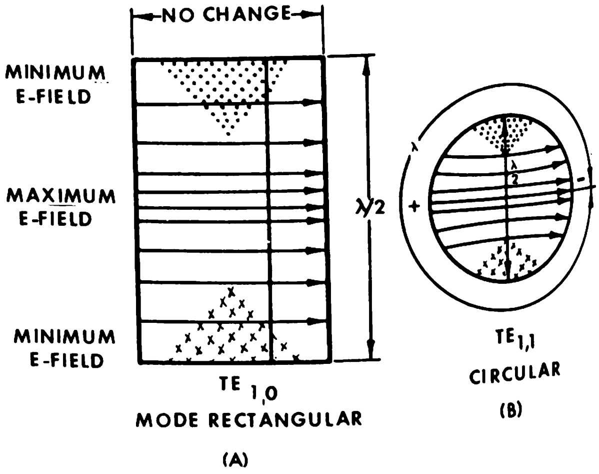

Figure 7-20.—How to count wavelengths for numbering modes.

E. Moving around the circumference g at the top, the field goes from zero, h maximum positive (tails of arrows), h zero, through maximum negative (head ows), to zero. This is one full wave, so mber is one. Going through the diameter, art is from zero at the top wall, through um in the center to zero at the bottom, lf wave. The second subscript is one. mplete designation for the circular mode es $TE_{1,1}$.

Several circular and rectangular modes are possible. On each diagram of figure 7-21 you can verify the numbering system.

The side view of the waveguides in figure 7-22 show that the magnetic and electric fields are maximum in intensity in the same area. This indicates that the current and voltage are in phase. This is the condition which exists when there are no reflections to cause standing waves.

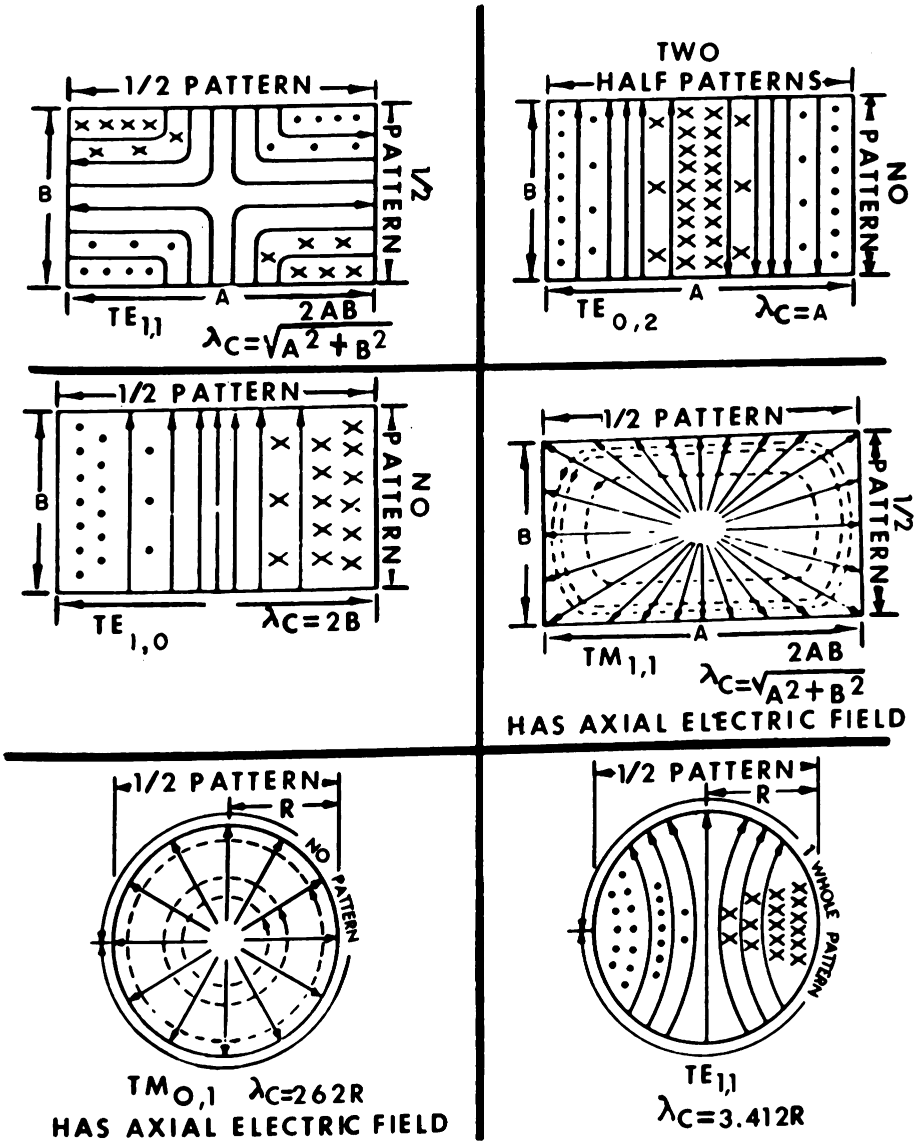

Figure 7-21.—Various modes in waveguides.

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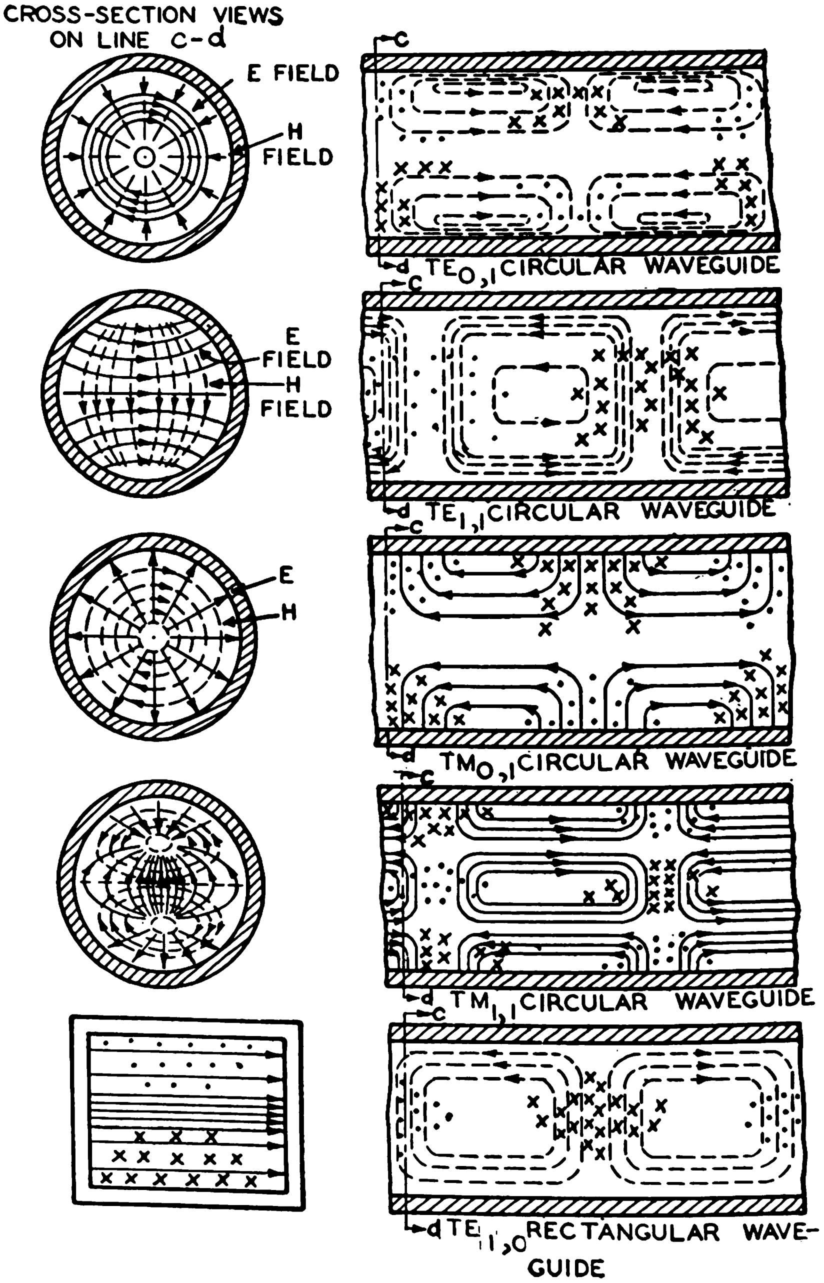

Figure 7-22.—Various modes in waveguides.

INTRODUCING FIELDS INTO A WAVEGUIDE

A waveguide, as was explained before, is a single conductor. Therefore, it does not have the two connections which ordinarly RF lines have, and it is necessary to use special devices to put energy into a waveguide at one end and to remove it from the other. In a waveguide, as with many other electrical networks, reciprocity exists in any excitation system—that is, energy may be transferred either to the waveguide or from the waveguide with the same efficiency.

Waveguides may be excited by three principal methods; namely, electric fields, magnetic fields, and electromagnetic fields.

Exciting With Electric Fields

When a small probe or antenna is placed in a vaveguide and fed with an RF signal, current vill flow in the probe and set up an electrostatic ield such as shown in figure 7-23 (A). This auses the E-lines to detach themselves from he probe and to form in the waveguide. When he probe is located in the right place, a field aving considerable intensity will be set up. 'he best place to locate the probe is in the enter, parallel to the narrow dimension and one-uarter wavelength away from the shorted end of ie guide, as shown in (C). Note here that the eld is strongest at the quarter-wave point. his is the point of maximum coupling between ie probe and the field. Of course, the probe ill work equally well at any point where E-ies exist with maximum intensity. For exnple, a good spot to place the probe would be three-quarter wave distance from the shorted d.

Usually, the probe is fed with a coaxial cable. comparison with the waveguide, this cable is tremely short. This insures that the greatest nefit will be derived from the waveguide. pedance matching between the coaxial cable d the waveguide is accomplished by varying the distance from the probe to the end of the waveguide (by moving the shorted end), and by varying the length of the probe (fig. 7-23 (B)). A mismatch will cause unwanted reflections in the waveguide.

The degree of excitation can be reduced by reducing the length of the probe, moving it out of the center of the E-field, or shielding it. Where it is necessary to vary the degree of excitation frequently, the probe is made retractable and the end of the waveguide fitted with a movable plunger. In airborne radar systems, the position of the probe and the end piece is often predetermined at the factory and fixed permanently.

In pulse-modulated radar systems there are wide sidebands on each side of the carrier. In order that a probe feeding system does not discriminate too sharply against frequencies which differ from the carrier frequencies, WIDE-BAND probes are often used. This probe is large in diameter and is conical or doorknob in shape. A conical probe is capable of handling high powered signals ((D) in fig. 7-23). The same kind of probe is used to take energy out of the guide and deliver it to the coaxial cable.

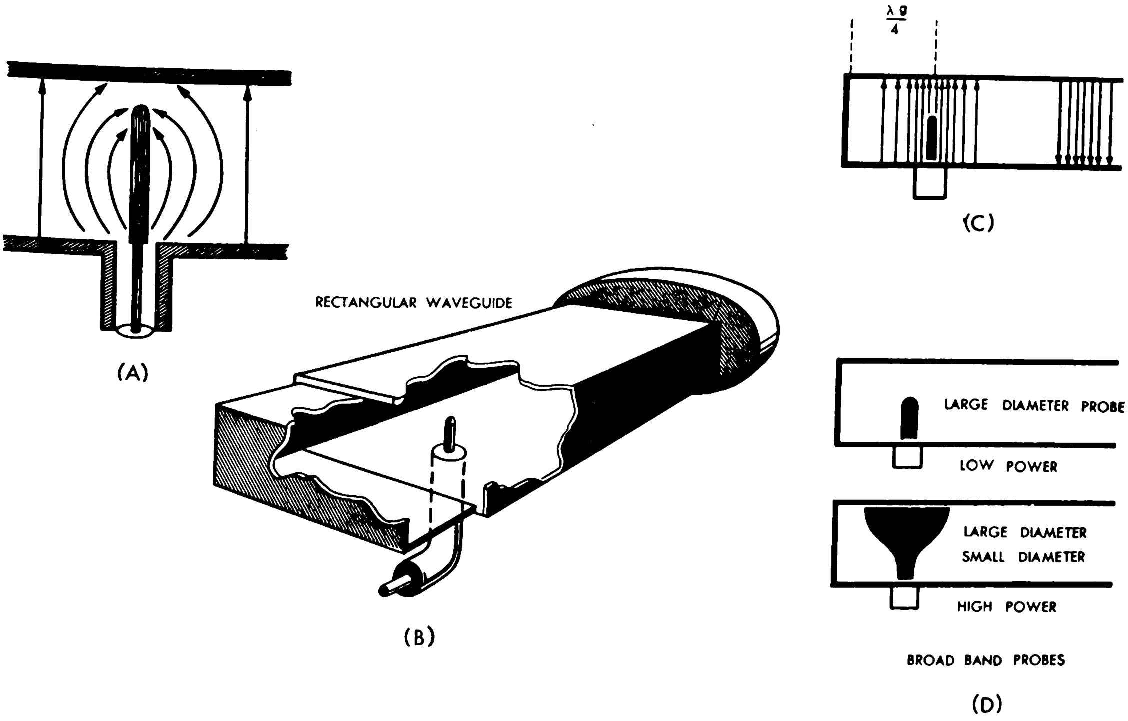

Figure 7-23.—Exciting the waveguide with electric field.

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Exciting With a Magnetic Field

Another way of exciting a waveguide is by setting up a magnetic H-field in the waveguide. This can be accomplished by placing a small loop, which carries a high current, in the waveguide. This is what occurs: A magnetic field builds up and expands until it fills the space within the waveguide. If the frequency of the current is correct, energy will be transferred from the loop to the waveguide. A loop for transferring energy into a guide is shown in figure 7-24 (A) and (B). Notice that the loop is fed by a coaxial cable. The location of the loop for optimum coupling to the guide is at the place where the magnetic field, which is to be set up, is of greatest strength. There are a series of places where this is true. Several are shown in (C).

When less coupling is desired, you can rotate or move the loop until it encircles a smaller number of lines of force.

When an excitation loop is used in radar equipment, its proper location is often predetermined and fixed either during construction or final tuning at the factory. In test or laboratory equipment, the loop is often made adjustable.

When a loop is introduced in a guide in which an H-field is present, a current will be induced in the loop itself. Thus, the loop may take energy out of the waveguide as well as put energy into it.

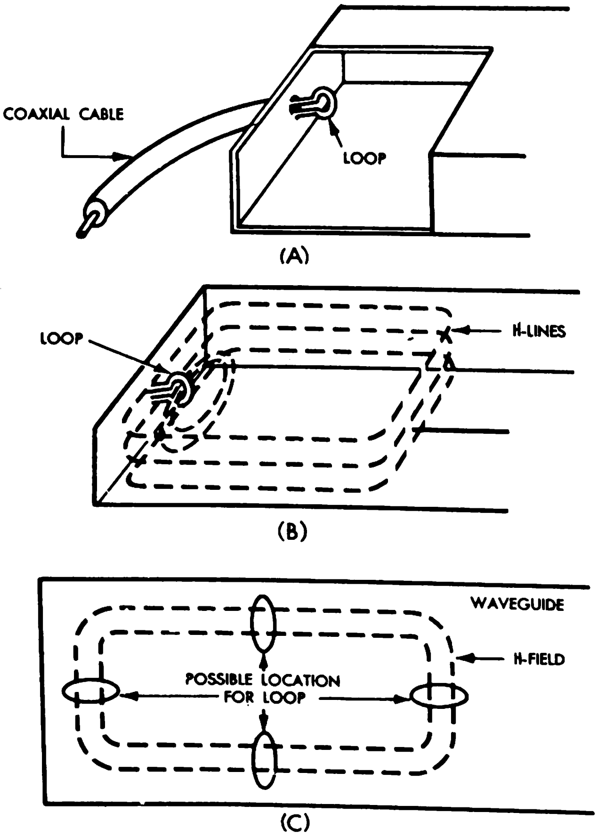
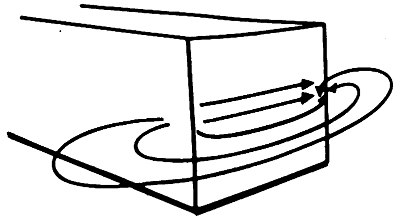


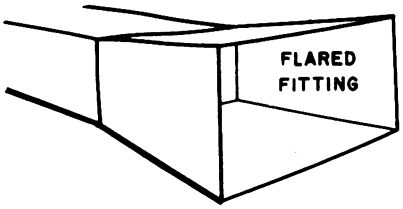
Figure 7-24.—Excitation with magnetic field.

Exciting With Electromagnetic Fields

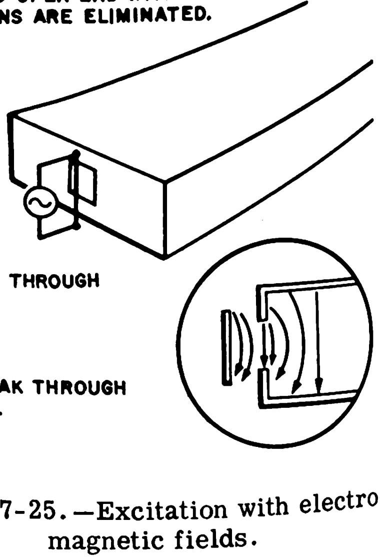
After learning what fields are like, you might think that a good way either to excite the waveguide or to couple energy out of it is simply to leave the end open. However, this is not the case, for when energy leaves a guide, fields exist around the end which result in mismatch, as shown in figure 7-25 (A). In other words,



(A) REFLECTIONS OCCUR FROM AN ORDINARY OPEN END DUE TO THE WAY FIELDS EXPAND AROUND OPENING.



(B) BY FLARING OPEN END WITH OPTIMUM PROPORTIONS, REFLECTIONS ARE ELIMINATED.



(C) EXCITATION THROUGH APERTURE.

(D) FIELDS LEAK THROUGH APERTURE.

Figure 7-25.—Excitation with electromagnetic fields.

lections and standing waves would result if
end were left open. Thus, simply leaving
end open is not an efficient way of letting
rgy out of the waveguide.

In order for energy to move smoothly in or
of a guide, the opening of the guide may be
red like a funnel, as shown in (B) of figure
5. This makes the guide similar to a V-type
enna. The funnel in effect eliminates re-
tion by matching the impedance of free space
the impedance of the waveguide. When the
th of the funnel is exposed to electromagnetic
ds, they enter and are gradually shaped to
he waveguide. The funnel is directional in
racteristic. It sends or receives the greatest
unt of energy in front of the opening.

nother method for either putting energy into
emoving it from waveguides is through slots
penings. This method is sometimes used
very loose coupling is desired. In this
od energy enters the guide through a small
ture, as you can see in (C). Any device
h will generate an E-field may be placed
the aperture and the E-field will expand
the waveguide. A single wire is shown in
n it E-lines are set up parallel to the wire
o the voltage difference between parts of
ire. The E-lines, in expanding, will exist
first across the aperture, then across the interior of the waveguide. If the frequency is correct and the size of the aperture properly proportioned, energy will be transferred to the waveguide with a minimum of reflections.

BENDS, TWISTS, JOINTS, AND TERMINATIONS

In order for energy to move from one end of a waveguide to the other without reflections, the size, shape, and dielectric material of the waveguide must be constant throughout its entire length. Any abrupt change in its size or shape results in reflections. Therefore, if no reflections are desired, any change in the direction or the size of the waveguide must be gradual. When it is necessary that the change in direction or size be abrupt, then special devices, such as bends, twists, joints, or terminations, must be used.

Bends

Waveguides may be bent in several ways to avoid reflections (fig. 7-26). One is to make the bend gradual. It must have a radius of bend

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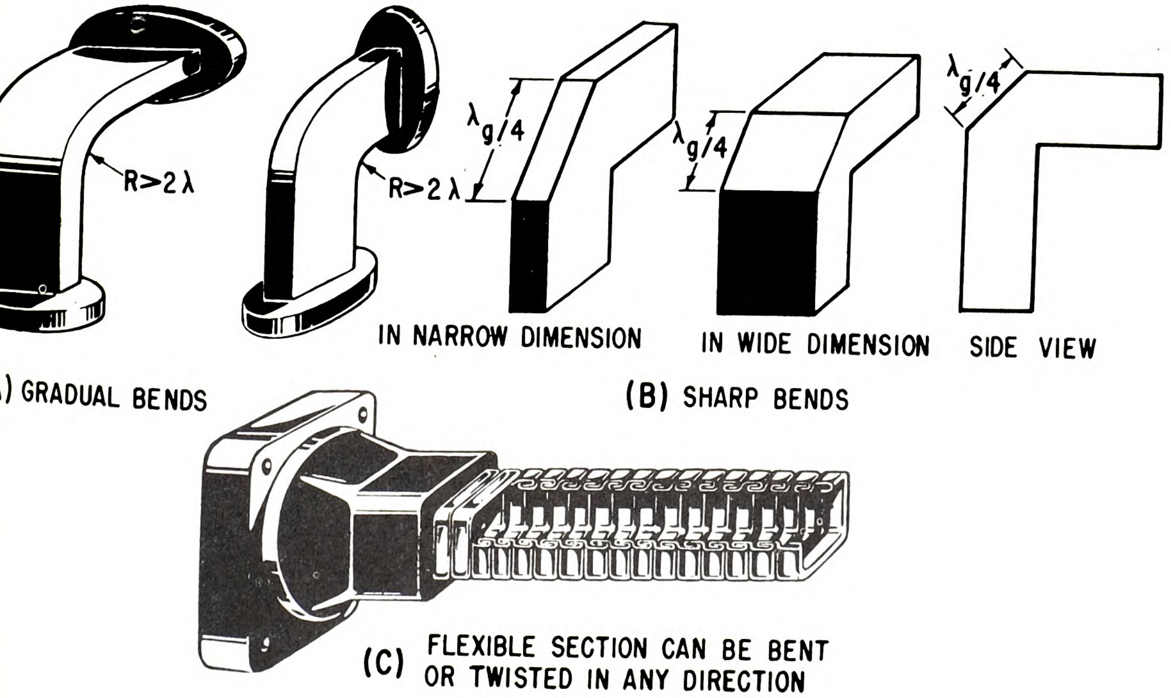


) GRADUAL BENDS

(B) SHARP BENDS

(C) FLEXIBLE SECTION CAN BE BENT OR TWISTED IN ANY DIRECTION

Figure 7-26.—Types of bends.

greater than two wavelengths in order to minimize any reflection. Some bends may be 90-degree bends; others may be greater or less than 90 degrees, depending upon the requirements of the system. Still another type of bend is the sharp bend.

A bend can be made in either the narrow or wide dimension of a guide without changing the mode of operation. Normally, in a sharp 90-degree bend, reflections will occur. To avoid this, the guide is bent twice at 45 degrees, one quarter wave apart. The combination of the direct reflection at one bend and the inverted reflection from the other bend will cancel and leave the fields as though no reflection had occurred.

To permit using any special bend which an installation might require, sections of a waveguide are often made flexible. These sections can be bent or twisted in any desired direction. They usually consist of a apiral wound ribbon of brass. In cross section the winding is exactly the same size as the waveguide. The entire assembly is like a spiral spring in that it can be bent or twisted into any desired shape. As skin effect keeps the current at the inner surface of the waveguide, the inside surfaces of the flexible section are chromium plated. This provides for maximum current conductivity. The outside of the section is covered with rubber. This gives the section flexibility and at the same time makes it both airtight and watertight.

Rotating the Field

Sometimes it is desired to rotate the electromagnetic fields so that they are in the proper direction for matching. This may be accomplished by twisting the waveguide (fig. 7-27). The twist should be gradual and extend over two wavelengths or more to prevent excessive reflections. Flexible sections also are used to rotate fields.

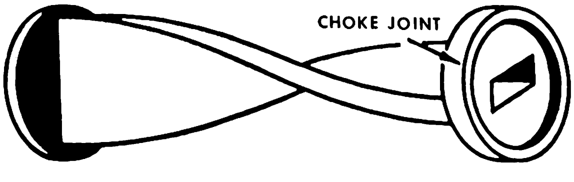


Figure 7-27.—Twisted section of waveguide rotates the field with minimum reflections.

Joints

Since it is impossible to mold an entire waveguide system in a radar set into one piece, it is necessary to construct it in sections, and then to connect the sections together by joints. There are three main types of joints. These are the permanent, the semipermanent, and the rotating joints.

On the surface it would appear that joining two waveguide sections together would only require that the sections be the same size and fit tightly at the joint. However, irregularities at the joints set up standing waves and allow energy to escape. One kind of joint which affords a good connection between the parts of a waveguide and which has very little effect on the fields is the PERMANENT TYPE. This joint is made at the factory. When it is used, the waveguide sections are machined within a few thousandths of an inch and then welded together. The result is a hermetically-sealed and mirror-smooth joint.

Where it is necessary that sections be taken apart for normal maintenance and repair, it is impractical to use a permanent joint. To permit portions of the waveguide to be taken apart, they are commonly connected together with semipermanent joints. The most common type of semipermanent joint is the choke joint. A cross-sectional view of a choke joint is shown in figure 7-28 (A). It consists of two flanges which are connected to the waveguide at the center. The right-hand flange is flat, and the one at the left is slotted a quarter wave deep at a distance a quarter wave from the point where the walls of the guide are joined. The quarter-wave slot is shorted at the end. The two quarter waves together become a half wave and reflect a short circuit at the place where the walls are joined together. Electrically, this creates a short circuit at the junction of the two waveguides. The two sections actually can be separated as much as a tenth of a wavelength without excessive loss of energy at this joint. This separation allows room to seal the interior of the waveguide with a rubber gasket for pressurization. The quarter-wave distance from the walls to the slot is modified slightly to compensate for the slight reactance introduced by the short space and the open circuit from the slot to the surface of the flange.

The name CHOKE JOINT is said to come from the similarity between the action of this joint on RF fields and the action of an RF choke in a power supply lead. An RF choke keeps RF in the circuit where it belongs. Similarly, the

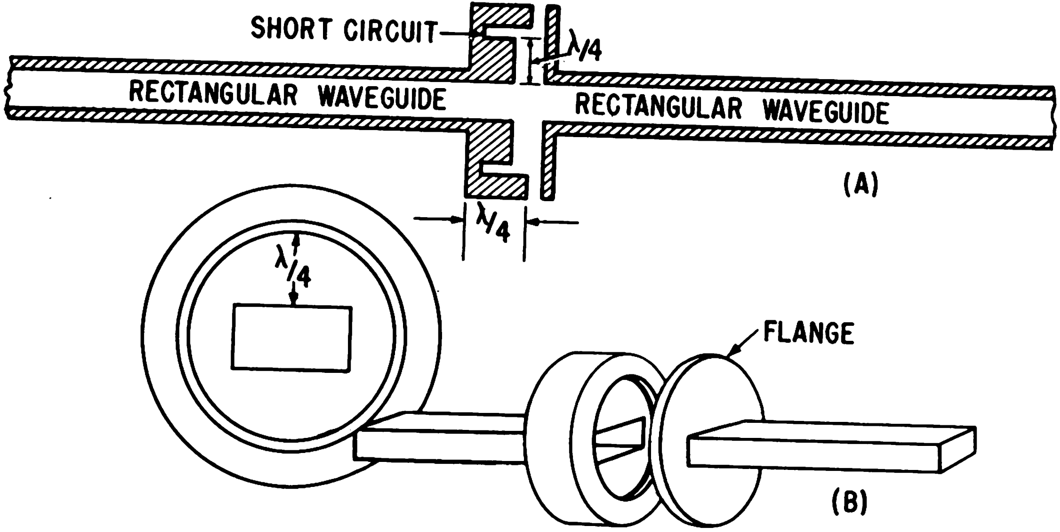
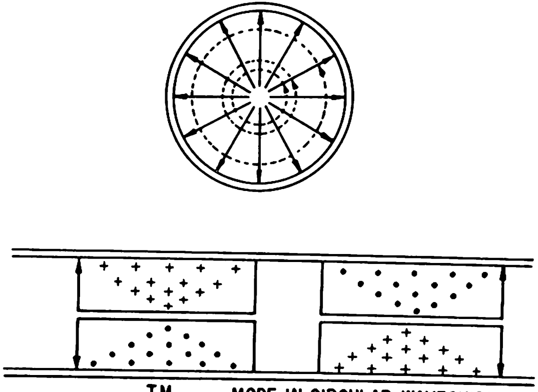


Figure 7-28.—Choke joints keep RF fields inside waveguide.

hoke joint keeps the electromagnetic fields in
ne waveguide where they belong. The loss in-
roduced by the well-designed choke is less than
.03 db, while a well-machined, unsoldered
ermanent joint has a loss of 0.05 db or more.

Rotating joints are usually required in an
rborne radar system where the transmitter is
ationary and the antenna is rotatable. A simple
ethod for rotating part of a waveguide system
by using a mode of operation that is sym-
etrical about the axis (fig. 7-29). This re-
irement is met by using a circular waveguide
d a mode such as $TM_{0,1}$. In this method a
oke joint may be used to separate the sections
echanically and to join them electrically. With
s method the waveguide rotates, but not the
ld. The continuous field produced by the fixed
ld minimizes reflections. Although this method
satisfactory, current airborne equipment uses
ctangular waveguides. This requires a dif-
ent system for connecting the sections of the
veguide. For mechanical reasons the rotating
nt must be circular and involves the use of a
xial cable, as shown in figure 7-30. This cable
vides axial symmetry of the fields and the
cular cross section for rotation. In the rota-
joint, a probe forms the end of the center
ductor of the coaxial cable. The probe takes
rgy from one waveguide. It is then conducted
ugh the coaxial cable and delivered through
her probe to the other waveguide.

The probe in the other waveguide is one end
ne center conductor. The center conductor
ains stationary with respect to one waveguide and rotates with respect to the other. To make the rotating electrical connection, the outer conductor can either be fitted with sliding contacts or with the tubing by a half-wave slot. The slot which is shorted at the end reflects a short at the junction of the two outer conductors. In this method, no mechanical contact is required between the two sections of the outer conductor. The inner conductor of the coaxial cable may be supported by insulating washers, if such are needed.



$TM_{0,1}$ MODE IN CIRCULAR WAVEGUIDE

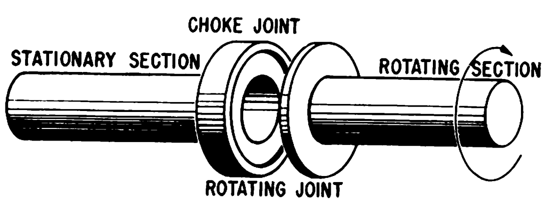


Figure 7-29.—Rotating joint and $TM_0, 1$ mode in circular waveguide.

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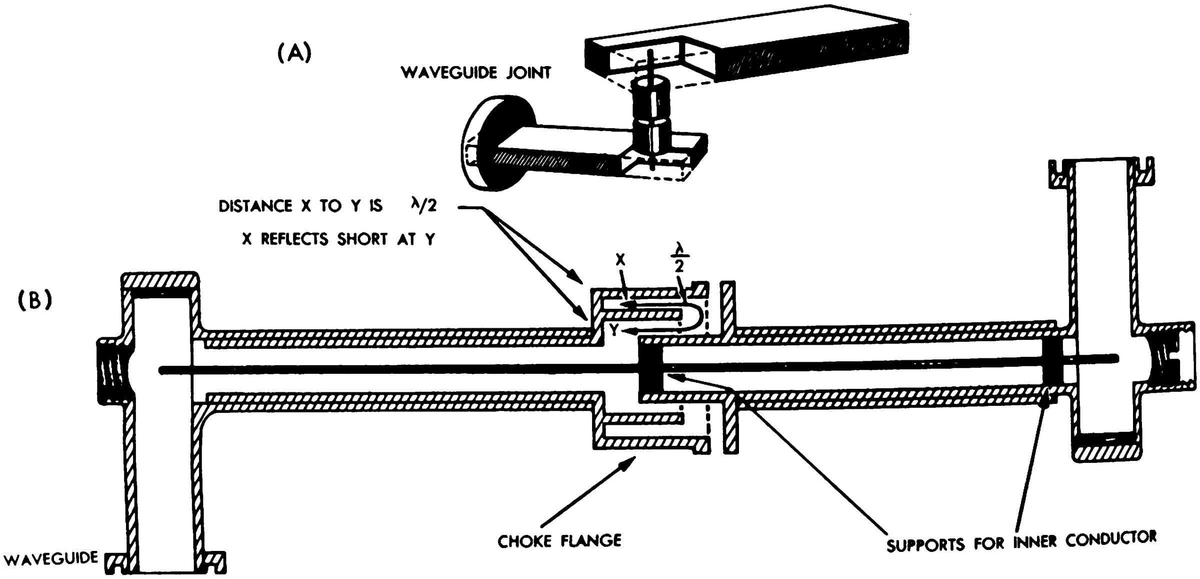

Figure 7-30.—Rotating joint with rectangular waveguide.

T-Junctions

Sometimes it is desirable to connect a section of waveguide into the side of another waveguide. This type of connection forms a T-junction. It may be connected either in the narrow side, as shown in figure 7-31 (A), or in the wide side of the waveguide, as shown in (D). When the T-junction is in the plane of an H-field of a $TE_{1,0}$ mode, it is called an H-TYPE junction, and when the junction is in the plane of the E-lines, it is called an E-TYPE junction.

The H-type junction is effectively a parallel connection with the main line. For example, when the end of the T-joint, (B) of figure 7-31, is short circuited at a distance of a half wave from the center of the waveguide, the result is the equivalent parallel circuit shown in (C). Note that (C) shows a half-wave section which is connected to a wire line. This section will reflect a short circuit at the line and will not allow any energy to pass. Similarly, in the waveguide itself a short circuit is reflected to the center, where the E-lines are supposed to be. Since an E-line cannot exist at a short circuit, no energy will pass that point. If the shorted end of the T-section were only a quarter wave from the center of the waveguide, an open section would be reflected there and the passage of energy would be unaffected.

The E-type joint is effectively a series connection with one side of the main line ((E) of fig. 7-31). Its two-wire counterpart is shown in (F). In this case, if the section added to the waveguide is a half wave long, it will act as a short at the junction but will allow the energy to pass. The length of the added section will have to be a quarter wave in order to open the circuit at the junction and stop the ordinary flow of energy past it.

One important use of the T-joint is with the automatic transmit-receive switch (also called the TR box). In the partial transmit-receive system, illustrated in figure 7-32, an H-type T-junction is connected in the main waveguide. The switching device in this illustration is known as an anti-TR (ATR). A spark gap (TR tube) is located one quarter wave from the center of the main guide. The junction is shorted at the distance of a half wave from the center of the main waveguide. When the powerful transmitter is turned on, a spark jumps the spark gap. This causes the waveguide branch to short at that point and is inverted to an open circuit at the center. Therefore, transmitted energy can pass unhindered.

Energy received from the radar echo enters the waveguide from the other end after the transmitter is turned off. This energy is not great enough to cause a spark to jump across the spark gap. This time the shorted end of the branch reflects a short at the center of the waveguide and reflects the received energy back to another T-junction, which is located at the input to the receiver. Thus no energy is

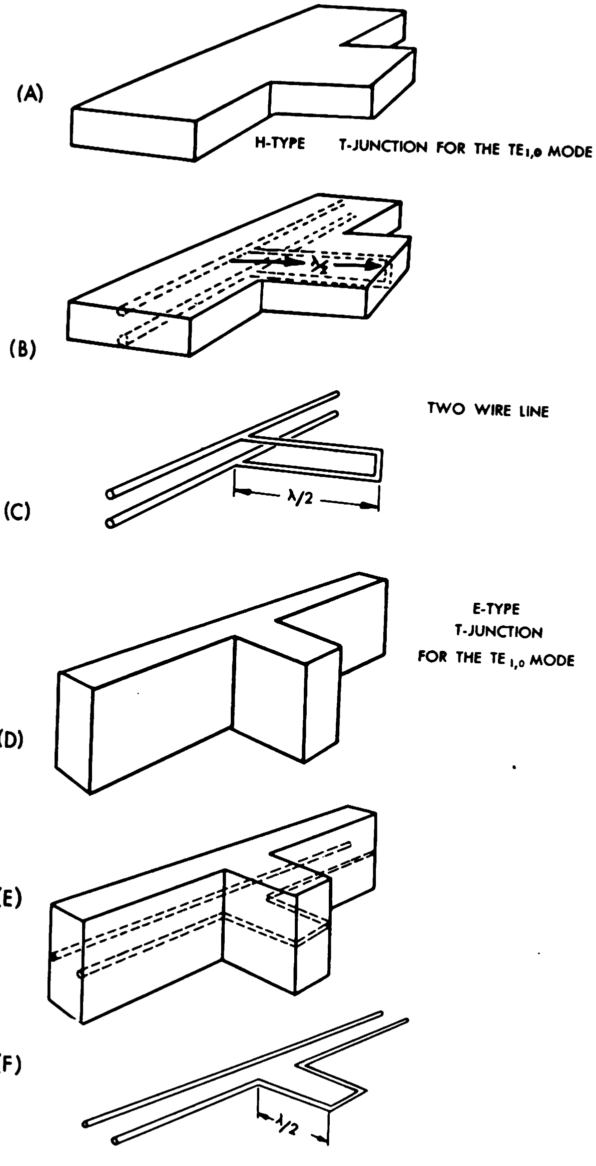

Figure 7-31.—T-junctions.

sorbed by the inoperative transmitter. There a similar arrangement called a TR box placed the waveguide leading to the receiver. It ers high impedance to the transmitted pulse low impedance to the received echo.

In practice the actual length of the sections T-junctions is not an exact quarter or a half elength because the E-fields and H-fields are perfect around the T-junction. A distortion ind the junction called FRINGE EFFECT uires some variations from exact wave- ths. A more detailed coverage of TR tubes iven later in the chapter under the heading plexer Systems.”

Matching Devices

Some devices which are used in radar introduce inductance or capacitance into the circuit. Sometimes these reactances are deliberately introduced. Other times when they are present and not desired, they can be tuned out with small fins or plates in a waveguide.

Figure 7-33 shows a number of reactive plates which are deliberately used to introduce capacity or inductance in a waveguide. When these plates are employed, as shown in (A), they set up oscillations in the higher modes. Since a waveguide is too small for higher modes at the same frequency, these frequencies are not propagated, but remain in the vicinity of the plates. If the edges of the plate are vertical with respect to the plane of the H-field, the modes produced are the TM type. The effect of this on power flow is that of inductance across the two-wire line. This causes reflections and a shift in the standing wave pattern. The wider the space between the plates, the greater the inductive reactance.

When the partitions are arranged perpendicularly to the E-field, as in (B) of figure 7-33, a local E-field and the higher modes of oscillation are set up between the edges of the plates. These oscillations cannot be propagated but do change the dominant mode to a TE mode and introduce capacitive reactance. As with the TM mode, the wider the opening, the greater the reactance.

From these facts it would seem that a resonant circuit might be produced by combining both types of plates and leaving a small opening in a large guide, as shown in (C) of figure 7-33. This is approximately true, providing the dimensions are correct. At resonance, a resonant circuit acts like high resistance. In this condition, a small opening would introduce a high shunt resistance and the guide would in effect have connected across it a resonant circuit, since at resonance a resonant circuit acts like a high resistance.

Terminating a Waveguide

Since a waveguide is a single conductor, its characteristic impedance (Z_0) is not as easy to define as that of a coaxial line. Nevertheless, you can think of the characteristic impedance of a waveguide as being approximately equal to the ratio of the strength of the electric field to

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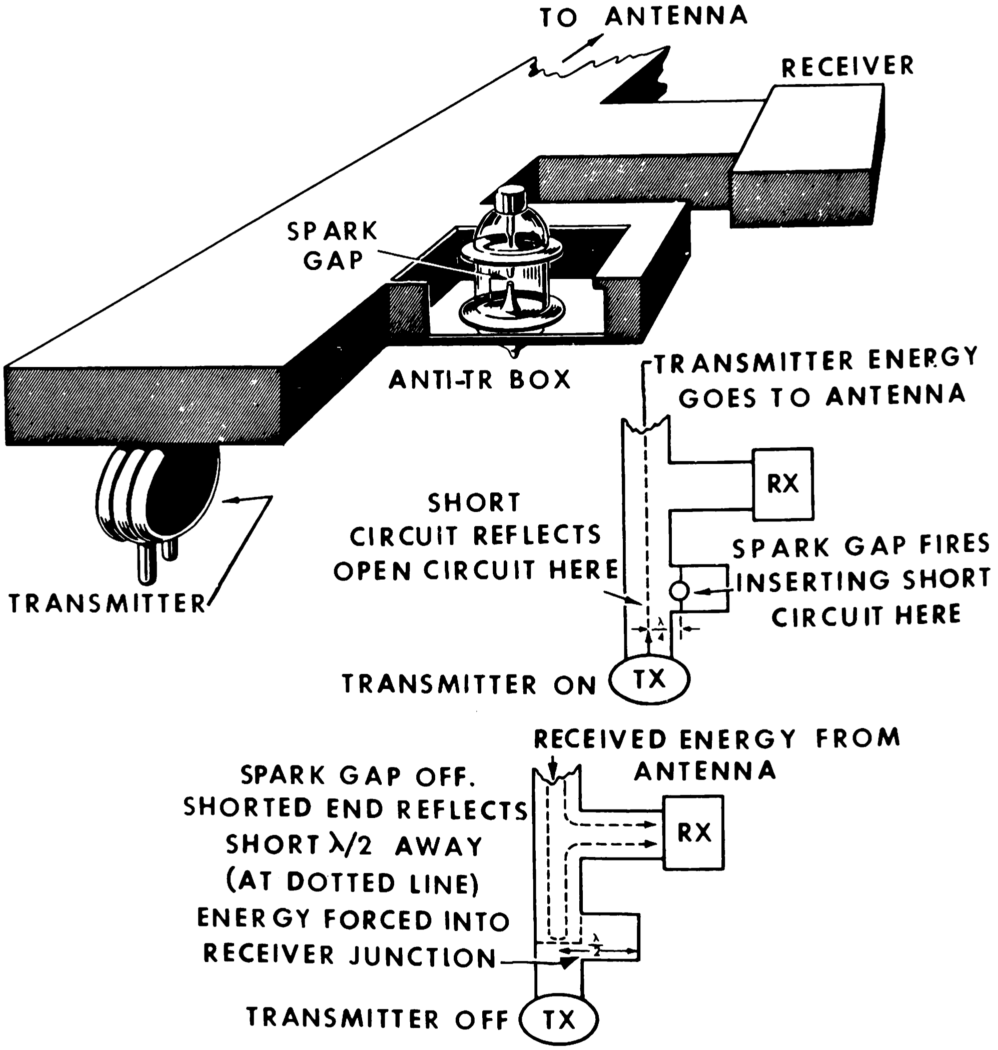
TO ANTENNA
RECEIVER
SPARK GAP
ANTI-TR BOX
TRANSMITTER
TRANSMITTER ENERGY GOES TO ANTENNA
RX
SHORT CIRCUIT REFLECTS OPEN CIRCUIT HERE
SPARK GAP FIRES INSERTING SHORT CIRCUIT HERE
λ/4
TRANSMITTER ON
TX
RECEIVED ENERGY FROM ANTENNA
SPARK GAP OFF. SHORTED END REFLECTS SHORT λ/2 AWAY (AT DOTTED LINE) ENERGY FORCED INTO RECEIVER JUNCTION
RX
λ/2
TRANSMITTER OFF
TX

Figure 7-32.—T-junction as a transmit-receive switch.

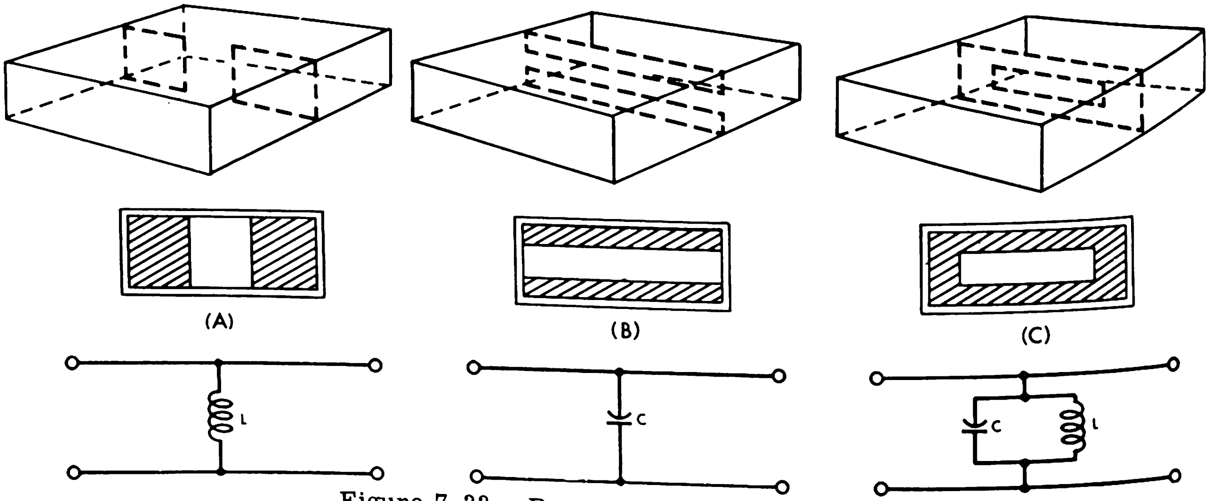

Figure 7-33.—Reactive plates in waveguide.

the strength of the magnetic field for energy traveling in one direction. This ratio is equivalent to the voltage-to-current ratio in coaxial lines on which there are no standing waves.

The lowest characteristic impedance of a circular waveguide is about 350 ohms. In a rectangular waveguide, it may be any value, depending on the dimensions of the waveguide and the frequency of the electrical energy. In this guide, it is directly proportional to the narrow dimension when the other dimension and the frequency are fixed, and may vary from approximately 0 to 465 ohms.

On a waveguide there is no place to connect a fixed resistor to terminate it in its characteristic impedance as there is on a coaxial cable. However, there are a number of special arrangements which accomplish the same thing. One consists of filling the end of the waveguide with graphite-sand, as shown in figure 7-34 (A). As the fields enter the sand, currents flow in it. These currents create heat, which is instrumental in dissipating energy. None of the energy hus dissipated as heat is reflected back into he guide. Another arrangement, (B) of the gure, uses a high resistance rod, which is laced at the center of the E-field. The E-field voltage) causes current to flow through the rod. he high resistance of the rod dissipates the nergy as an I^2R loss. Still another method for rminating a waveguide is to use a wedge of high resistance as shown in (C). The plane of the wedge is placed perpendicular to the magnetic line of force. When the H-lines cut the wedge, a voltage is induced in it. The current produced by the induced voltage on flowing through the high resistance of the wedge produces an I^2R loss. This loss is dissipated in the form of heat. This permits very little energy to reach the closed end to be reflected. These terminations are used as transmitter dummy loads for testing and shop operation. They are generally constructed with external fins which give a larger radiation surface, thus better heat dissipation.

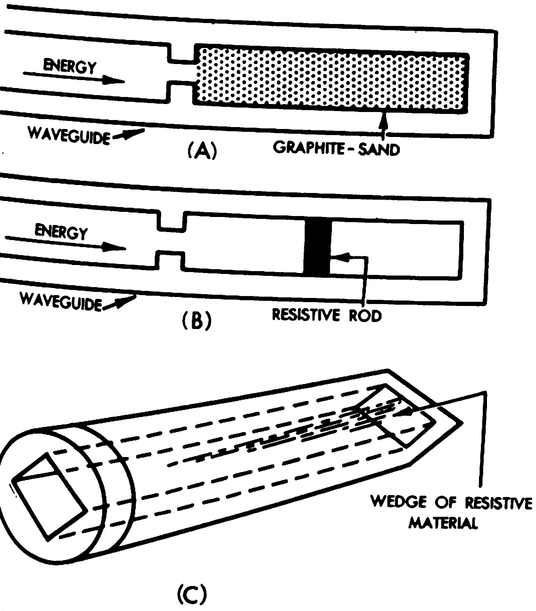

Figure 7-34.—Termination for minimum reflections.

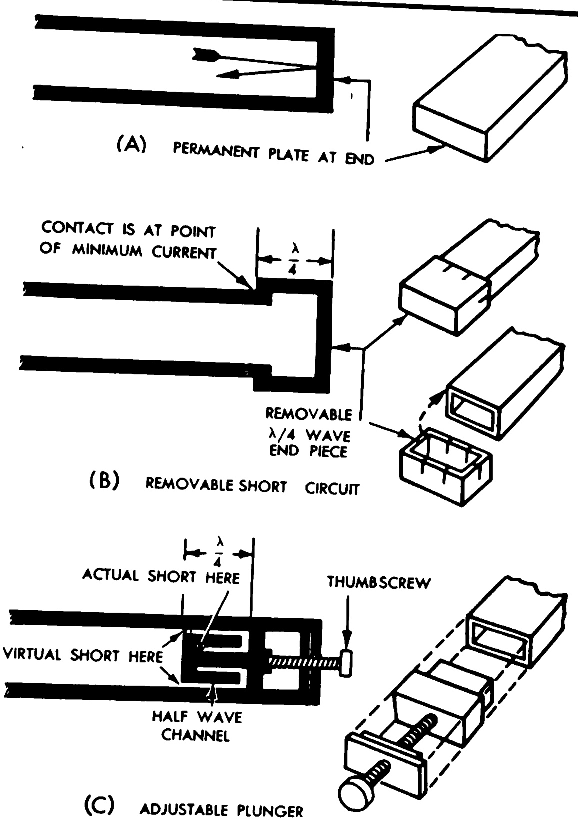
(A) PERMANENT PLATE AT END
CONTACT IS AT POINT OF MINIMUM CURRENT
λ/4
REMOVABLE λ/4 WAVE END PIECE
(B) REMOVABLE SHORT CIRCUIT
λ/4
ACTUAL SHORT HERE
THUMBSCREW
VIRTUAL SHORT HERE
HALF WAVE CHANNEL
(C) ADJUSTABLE PLUNGER

Figure 7-35.—Termination for maximum reflections.

Each of the preceding terminations is designed to match the impedance of the guide in order to insure a minimum of reflection. On the other hand, there are many instances where it is desirable for all the energy to be reflected from the end of the waveguide. The best way to accomplish this is to weld a permanent metal plate at the end of the waveguide. (See fig. 7-35 (A).)

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When it is necessary that the end be removable, a removable end plate is attached to the end of the guide. For this method to be satisfactory, the contact between the guide and the end plate must be exceptionally good in order that the H-field will not be attenuated when current flows. Perfect contact is not required when the connection is made at a point of minimum current. This point is located a quarter wave from the end. When connection is made at this point, a cup is used, as in (B), instead of the end plate. This cup is a quarter wave long and large enough to fit over the end of the guide. The voltage between opposite sides of the cup opening is high, but as the reflected H-field cancels the incident H-field, the resulting current is very small and reflection is at a minimum.

When the end must be adjustable, the contact must be nearly perfect. However, it is impossible to get a perfect contact. The best arrangement, one which is similar to the choke joint previously explained, consists principally of an adjustable plunger which fits into the guide as shown in (C). The walls of the waveguide and the plunger form a half-wave channel. The half-wave channel is closed at one end and reflects a short circuit across the other end, where a perfect connection is supposed to exist between the wall and the plunger. The actual physical contact is made at a quarter-wave distance from the short circuit, where the current is minimum due to the standing waves. This makes it possible for the plunger to slide loosely in the guide at a point where the contact resistance to current flow is very low.

Directional Couplers

Directional couplers are devices used to couple test equipment to a waveguide and are commonly included as a permanent section of the transmission line. They are used for measuring power in the waveguide, such as radar transmitter power output; also, they are used to inject a signal of known power into the waveguide in order to determine receiver sensitivity. Directional couplers have a fixed amount of attenuation which is generally stamped on the coupler. This type of coupling is used extensively for it contains no moving parts and injects negligible reflection into the waveguide.

A directional coupler couples energy from a wave going in one direction in a guide but not from a wave going in the other direction. There are two types of directional couplers—TWO-HOLE and ONE-HOLE.

A two-hole directional coupler is shown in figure 7-36 (A). In (B) of this figure note that a wave traveling to the right in the bottom guide has two paths into the upper guide, one from A to D directly and one from A to D via path B-C. However, the two paths differ in length by one-half wavelength, so that waves arriving by both paths interfere destructively, and no wave proceeds to the left in the upper guide. Also note that waves going to the right in the upper guide are lost in the absorbing material. However, if the wave in the main guide moves to the left, then the two paths by which waves arrive at point D (path B-C-D and path B-A-D) are equal in length and a wave proceeds to the left in the upper guide, and is picked up by the test equipment probe. Thus, energy from the transmitter passing to the left in the guide will reach the test equipment connection with a desirable amount of fixed attenuation, but energy picked up by the antenna which passes to the right will not reach the test equipment. A signal injected at the test equipment probe will travel toward the receiver (which is between the directional coupler and transmitter) but will not pass to the left toward the antenna.

The one-hole directional coupler is shown in figure 7-37. The coupling from the main guide to the branch is done by the electric and magnetic fields. The phase of the magnetic field is changed by the coupling so that the waves in the branch are cancelled in one direction and reinforced in the other. In contrast to the two-hole coupler, the one-hole coupler transmits a wave in a direction opposite to that of the wave in the main line. The proper coupling to secure the directional characteristic depends on the orientation angle between the main guide and the branch guide and the size of the hole between the two guides.

The branch guide is terminated at one end with a resistive material to absorb unwanted power, and the other end is connected to a probe for connection to the test equipment.

CAVITY RESONATORS

In ordinary radio work the conventional low-frequency resonant circuit consists of a coil and capacitor which are connected either in series or in parallel as in figure 7-38 (A). To increase

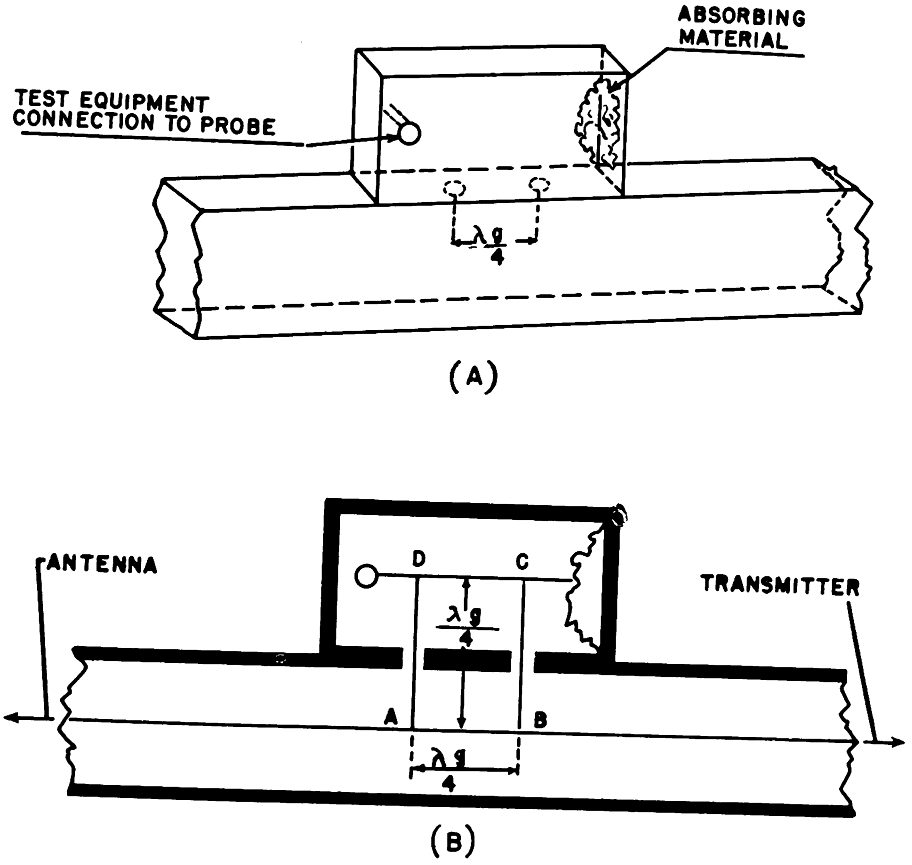

Figure 7-36.—Two-hole directional coupler.

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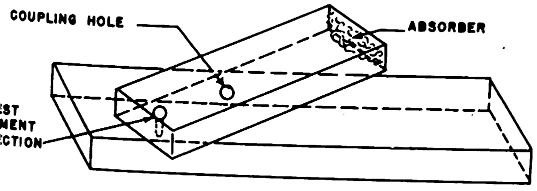


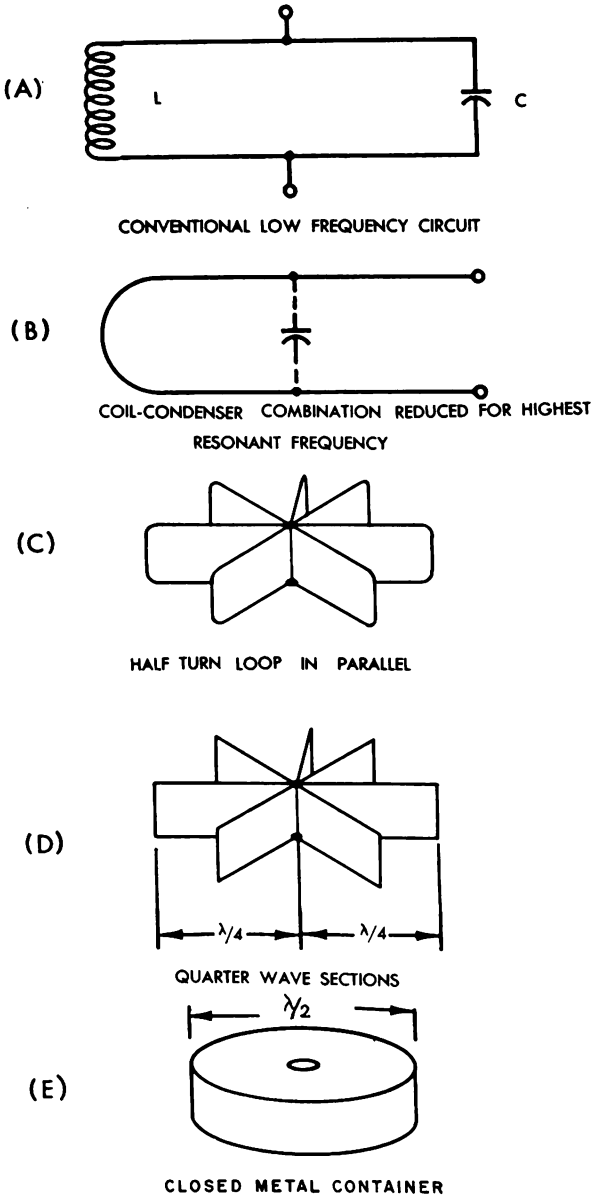
ure 7-37.—One-hole directional coupler.

esonant frequency, it is necessary to de- e either the capacitance or the inductance th. However, a frequency is reached where iductance is a half-turn coil and where the itance consists only of the stray capacitance coil. At extremely high frequencies this int circuit would consist of a coil about h long and a quarter inch across. In this t the current handling capacity and break- oltage for the spacing would be low.

The current carrying ability of a resonant circuit may be increased by adding half-turn loops in parallel. This does not change the resonant frequency appreciably because it adds capacitance in parallel, which lowers the frequency, and inductance in parallel, which increases the frequency. As the effects of each cancel, the frequency remains about the same.

In figure 7-38 (C), several half-turn loops are added in parallel. In (D) are shown several quarter wave Lecher lines, in parallel, which are resonant when they are near a quarter wavelength. When more and more loops are added in parallel, the assembly eventually becomes a closed resonant box as shown in (E) which is a quarter wave in radius or, in other words, a half wave in diameter. This box is called a RESONANT CAVITY.

A resonant cavity displays the same resonant characteristics as a tuned circuit com-



(A) CONVENTIONAL LOW FREQUENCY CIRCUIT

(B) COIL-CONDENSER COMBINATION REDUCED FOR HIGHEST RESONANT FREQUENCY

(C) HALF TURN LOOP IN PARALLEL

(D) QUARTER WAVE SECTIONS

(E) CLOSED METAL CONTAINER

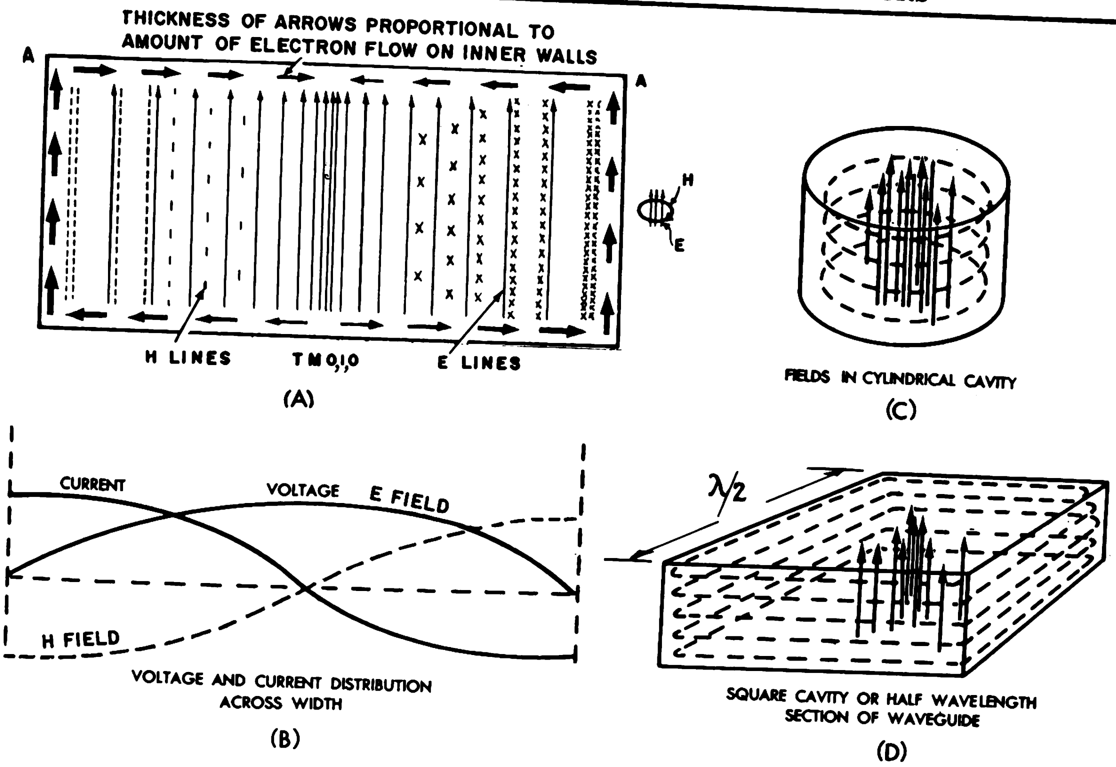
Figure 7-38.—Development of cavity from quarter-wave sections.

posed of a coil and capacitor. In it there are a large number of current paths. This means that the resistance of the box to current flow is very low and that the Q of the resonant circuit is very high. While it is difficult to attain a Q of several hundred in a coil of wire, it is fairly easy to construct a resonant cavity with a Q of many thousand. Although a cavity is as efficient at low frequencies as at high frequencies, the large size required at low frequencies prohibits its use at those frequencies. For example, at one megacycle a resonant cavity would be a cylinder about 500 feet in diameter. When the frequency is in the vicinity of 10,000 megacycles, the diameter of the cavity is only 0.6 inch. This makes the cavity smaller than a conventional tuned circuit. Therefore, equipment which operates at a frequency of approximately 3,000 mc. or above employs resonant cavities extensively.

The Fields in a Cavity

A resonant cavity may be compared to a waveguide, since its operation is best described in terms of the fields rather than in terms of the currents and voltages present. As in waveguides, the different field configurations in cavities are called MODES. In figure 7-39, in which the dominant mode of the cylindrical cavity is shown, note that in (A) the voltage is represented by E-lines between the top and the bottom of the cavity. The current, due to skin effect, flows in a thin layer of the surface of the cavity. The strength of the current is indicated by arrows of various lengths. The magnetic field is strong where the current is high. The strongest H-field is at the vertical walls of the cylinder and diminishes toward the center where the current is zero. This is due to the standing waves on the quarter-wave section. The E-field is maximum at the center and decreases to zero at the edge, where the vertical wall is a short circuit to the voltage. The curves of E-field and H-field density are shown in figure 7-39 (B); two types of cavities with their fields represented are shown in (C) and (D).

The modes in a cavity are identified by the same numbering system that is used with waveguides, except that a third subscript is used to indicate the number of patterns of the transverse field along the axis of the cavity (perpendicular to the transverse field). For example, the cylindrical cavity shown in (C) of figure 7-39 is a form of circular waveguide. The axis is the center of the circle. The transverse field is the magnetic field. Therefore, it is TM (transverse magnetic). Around the circumference there is a constant magnetic field. (The H-lines are parallel to the circumference.) Therefore, the first subscript is zero. The distance across the diameter is one-half wave. Thus the second subscript is one. Through the


THICKNESS OF ARROWS PROPORTIONAL TO AMOUNT OF ELECTRON FLOW ON INNER WALLS
A
A
H
E
H LINES
TM 0,1,0
E LINES
CURRENT
VOLTAGE
E FIELD
H FIELD
λ/2

(A)

FIELDS IN CYLINDRICAL CAVITY

(C)

VOLTAGE AND CURRENT DISTRIBUTION ACROSS WIDTH

(B)

SQUARE CAVITY OR HALF WAVELENGTH SECTION OF WAVEGUIDE

(D)

Figure 7-39.—Voltages, currents, and associated fields for simple modes in a cavity resonator.

ter, along the axis, the H-field strength is onstant zero. This makes the third subscript o. Therefore, the complete description of the le is TM$_{0,1,0}$.

When a section of waveguide which is one- wave long is closed on both ends in the n of a rectangular cavity, as shown at (D) gure 7-39, standing waves are set up and nance occurs. The simple mode in this y is the same as the dominant mode of a angular waveguide, that is, it is TE$_{1,0}$. third subscript of the mode, which is rmined by the plane of the E-field, is one. the complete description of the simple in the rectangular cavity in (D) is TE$_{1,0,1}$ sverse electric).

avities may have various physical shapes. amber enclosed in conducting walls may ate at several frequencies and produce a er of modes, depending upon its size and . Figure 7-40 shows several types of es. (Note the large approximate Q values ted in some cases.) Of those shown the er type cavity is useful in wavemeters or in frequency measuring devices. The cylindrical ring type is used in superhigh-frequency oscillators as the frequency determining element. The section of waveguide which is shown diagrammatically is used in some radar systems as a mixing chamber for combining signals from two sources.

Exciting the Cavity

There are three principal ways in which energy can be inserted into and removed from a cavity resonator (fig. 7-41). The first is by inserting a probe into the cavity. The current which flows in the probe sets up E-lines parallel to it, and they in turn start oscillation. Another method uses a magnetic loop. The loop is placed in the region where the magnetic field will be located. The currents in the loop start an H-field in the cavity. Either of these methods can be used to remove energy from or to put energy into the cavity. A third method uses a cylindrical ring type cavity. In this method the

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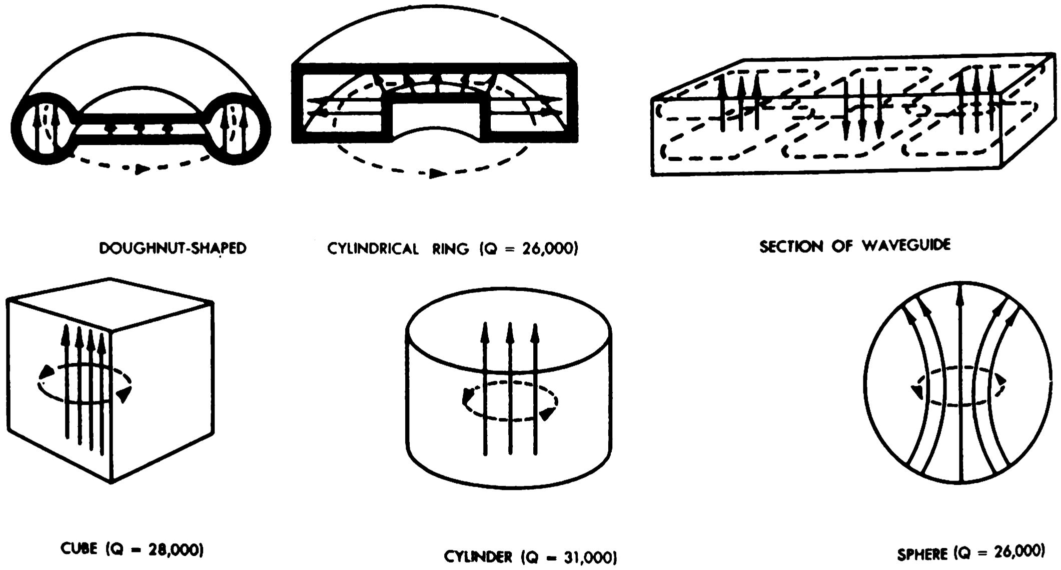


Figure 7-40.—Several types of cavities.

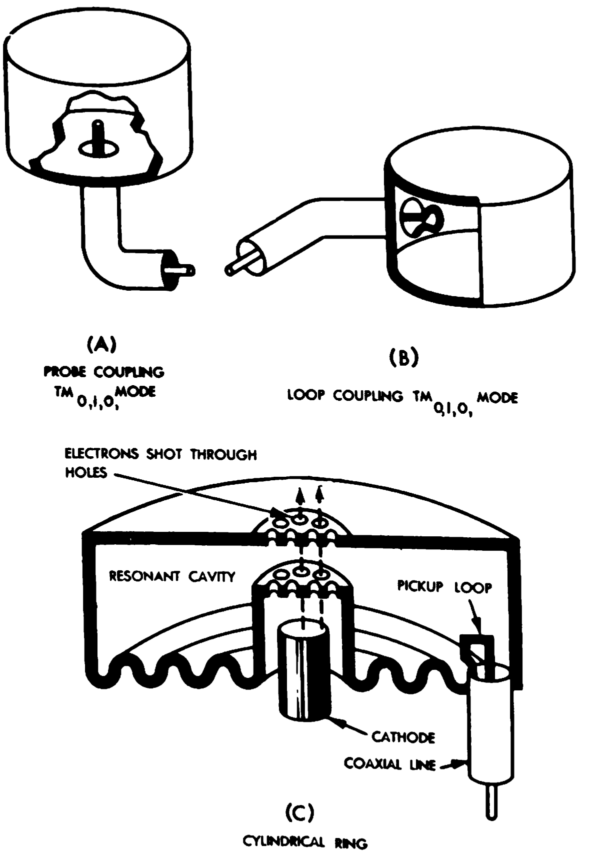

(A)
PROBE COUPLING TM 0,1,0, MODE
(B)
LOOP COUPLING TM 0,1,0, MODE
ELECTRONS SHOT THROUGH HOLES
RESONANT CAVITY
PICKUP LOOP
CATHODE
COAXIAL LINE
(C)
CYLINDRICAL RING

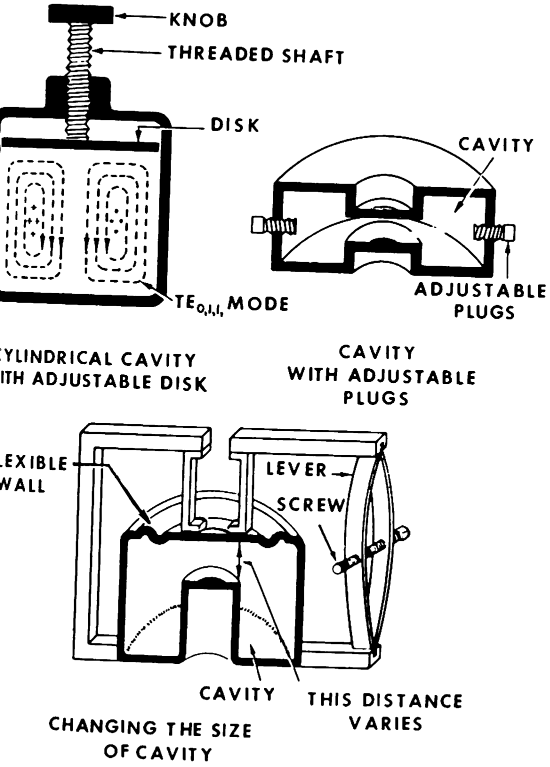
Figure 7-41.—Methods of exciting the cavity.

energy is placed into the cavity by clouds of electrons, which are virtually shot through the holes in the center of a perforated plate. As each cloud goes through, it creates a disturbance in the space inside the cavity until a field is set up. In terms of current, it may be said that the approaching cloud of electrons makes the perforated plate positive by repelling the electrons away from it. This current starts an H-field. Energy may be removed from the cavity by placing a loop at the outside edge.

Other methods of feeding the cavity are discussed later in the analysis of systems using cavities.

Varying the Resonant Frequency of the Cavity

Three methods for setting the resonant frequency in a cavity are shown in figure 7-42. One method uses a cylindrical cavity with an adjustable disk. When a $TE_{0,1,1}$ mode is used, the size of the cylinder may be changed along the axis to change the resonant frequency. The smaller the volume of the cavity, the higher the resonant frequency. The movement of the disk may be calibrated in terms of frequency. Usually in the case of high-frequency equipment a micrometer scale is used to indicate the position of the disk, and a calibration chart is used to determine the frequency.



YLINDRICAL CAVITY
ITH ADJUSTABLE DISK

CAVITY
WITH ADJUSTABLE
PLUGS

CHANGING THE SIZE
OF CAVITY

Figure 7-42.—Methods of changing the frequency of a cavity.

second method for varying the frequency oys threaded plugs which are inserted in the of the cavity. The plug reduces the gth of the magnetic field in the cavity in a er similar to reducing the inductance of ned circuit. The deeper the plug extends he cavity, the higher the frequency.

the third method, the interior of the , which is part of the interior of a vacuum is sealed and evacuated. In this method quency change occurs whenever the top ottom of the cavity are moved away from ward) each other. This is accomplished ning a screw at the end of a lever. As the ce varies, the volume and the capacity en the top and bottom of the cavity are ed. As the change in capacity is the chief of the change in the distance between the , the resonant frequency is inversely tional to the distance from the top to tom.

ther way of changing the frequency is by g the method of exciting the circuit. an be done by tuning the exciting loop capacitively or inductively. This can occur either accidentally due to improperly tuned circuits or deliberately as a means of tuning the cavity.

Uses of Cavities

There are many ways in which resonant cavities are used in electronics. For example, the klystron in figure 7-43 (A), which is usually

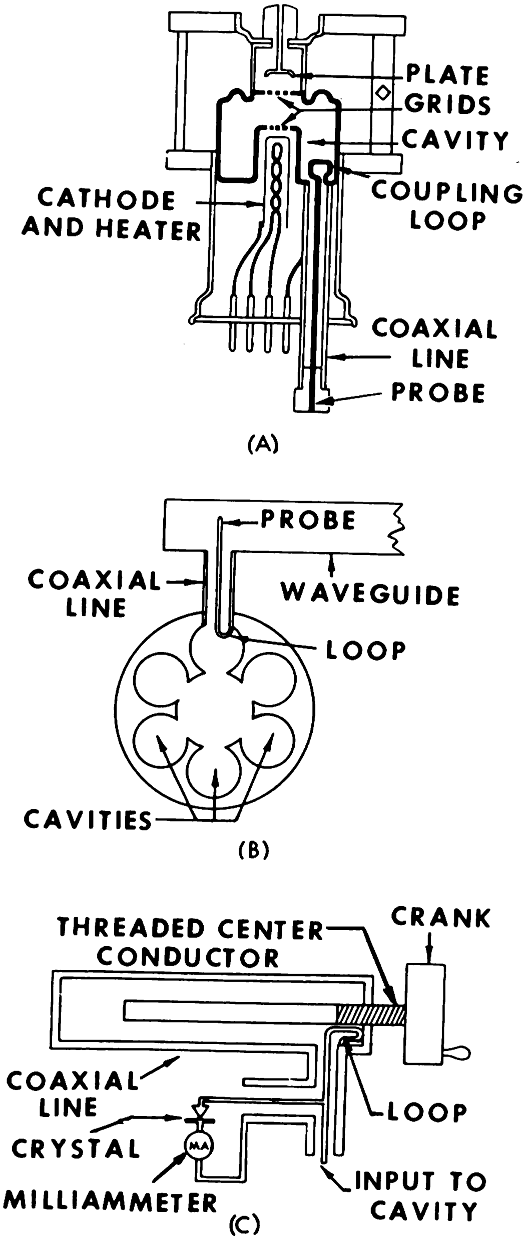


Figure 7-43.—Uses of cavities.

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the local oscillator in a radar receiver, is tuned by the resonant cavity previously shown in figure 7-41 (C). In the klystron, the cathode emits electrons which pass through the grids toward the plate. When they pass through this area, they disturb the field and excite the cavity. The resonant frequency is changed by the spacing of the grids. Another use of resonant cavities is the series of cavities arranged around a circle in the magnetron oscillator as shown in (B) of figure 7-43. These cavities, which are coupled one to another through capacitance at the openings, are excited by moving electrons. The energy from the electrons is passed around the ring from all cavities to the one with a loop. This one serves to transfer the energy to the waveguide. From the waveguide, the energy travels to the antenna where it is radiated into space.

Tunable magnetrons are used in some equipments in order that the transmitter frequency may be varied. Although most magnetrons used are of the fixed frequency type, they possess characteristics, other than cavity dimensions, which will determine their output frequency and mode of oscillation. These characteristics will be explained in chapter 8.

Cavities also may be used as wavemeters (devices for measuring frequency). One type of wavemeter consists of a CYLINDRICAL cavity with an adjustable disk. Another type operates essentially like this but employs a COAXIAL cavity and operates in a different mode, as shown in figure 7-43 (C). In the second type, the signal is introduced into the cavity by a loop which is located in one end of the cavity. The signal is strongest when the loop is at a high current point in the standing wave. The standing wave of current is maximum at odd multiples of quarter-wave distances along the center conductor. When the length of the threaded center conductor is varied by the crank, the distance from the end to the loop can be made equal to an odd multiple of quarter waves. This causes the current maximum to occur at the loop and the input impedance at the loop to be minimum.

The threaded shaft shown in (C) of figure 7-43 can be calibrated either in wavelength or in frequency. The input impedance can be indicated by any suitable indicator, such as a crystal rectifier and a d-c milliammeter. In operation, when the input impedance is minimum, the signal will be absorbed by the cavity. In this case, the meter reading will drop. To check the frequency of the applied signal turn the crank until a dip occurs on the meter and read the frequency on the threaded shaft. To check the frequency for a zero impedance reading, turn the crank until a dip occurs on the meter and read the frequency on the threaded shaft.

A cavity can be used as a mixing chamber. When two or more signals are put into a cavity, it is possible to remove the combination of their signal voltages. An example of this use is discussed later in this chapter.

Another use of a cavity is as an impedance matching device such as shown in figure 7-44, which illustrates a small waveguide connected to a large waveguide. Normally, when you connect the two waveguides together, there will be reflections in the waveguides. However, a small section of waveguide of an intermediate size can be matched without reflections, provided that plates are used at the junction to cancel the reactive effects which result from the different sizes of the waveguides. Thus, although the cavity itself has standing waves in it, there are none on either waveguide.

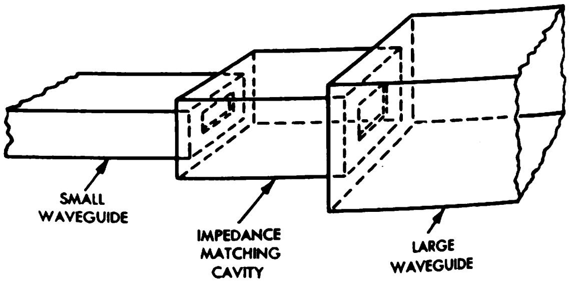

Figure 7-44.—Cavity used as an impedance matching device.

The ECHO BOX uses a cavity as a RINGING CIRCUIT in a resonant circuit. The ringing circuit gets its name from the fact that it oscillates for many cycles after being started by an external circuit. In this use the cavity is resonant, and once oscillation is started it will continue for a few microseconds after the source of voltage has been removed. This action is analogous to a bell which will ring for many seconds after being struck. In the 3 cm. (10,000 mc.) ringing circuit shown in figure 7-45, the cavity itself is a cylinder which is three inches in diameter and 10 inches long. A movable piston in the cylinder determines the volume

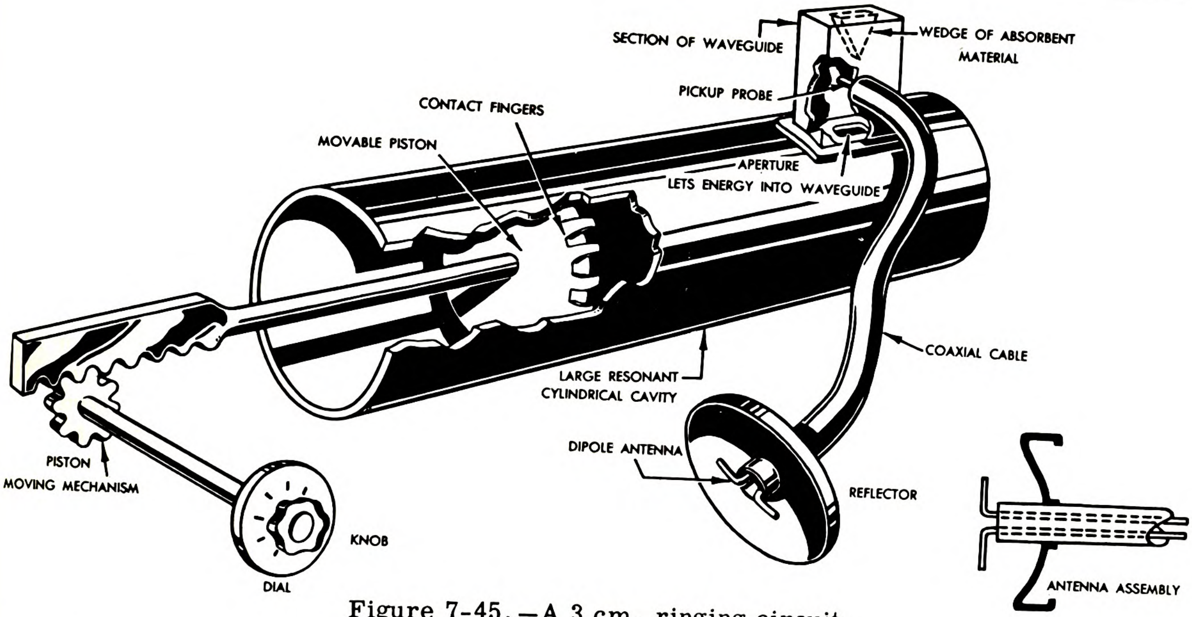

Figure 7-45.—A 3 cm. ringing circuit.

the cavity. As the position of the piston is
ibrated in megacycles, it serves as a fre-
ency meter. The cavity is energized by a
nal which enters through a small aperture
m the small section of waveguide. The energy
induced in the short waveguide by a probe,
ch in turn is fed by a coaxial cable. A good
hod of feeding the signal into the coaxial
le is by connecting a small antenna to the
of the cable.

The resonant cavity just described is used as an echo box in figure 7-46. Echo boxes are resonant cavities which have a very high Q. They are used with microwave radar sets to provide an artificial or ''phantom'' target, which may be used to tune the receiver to the transmitter operating frequency.

This is how the echo box works. When the radar transmitter pulses, energy is fed into the echo box cavity. There it sets up violent

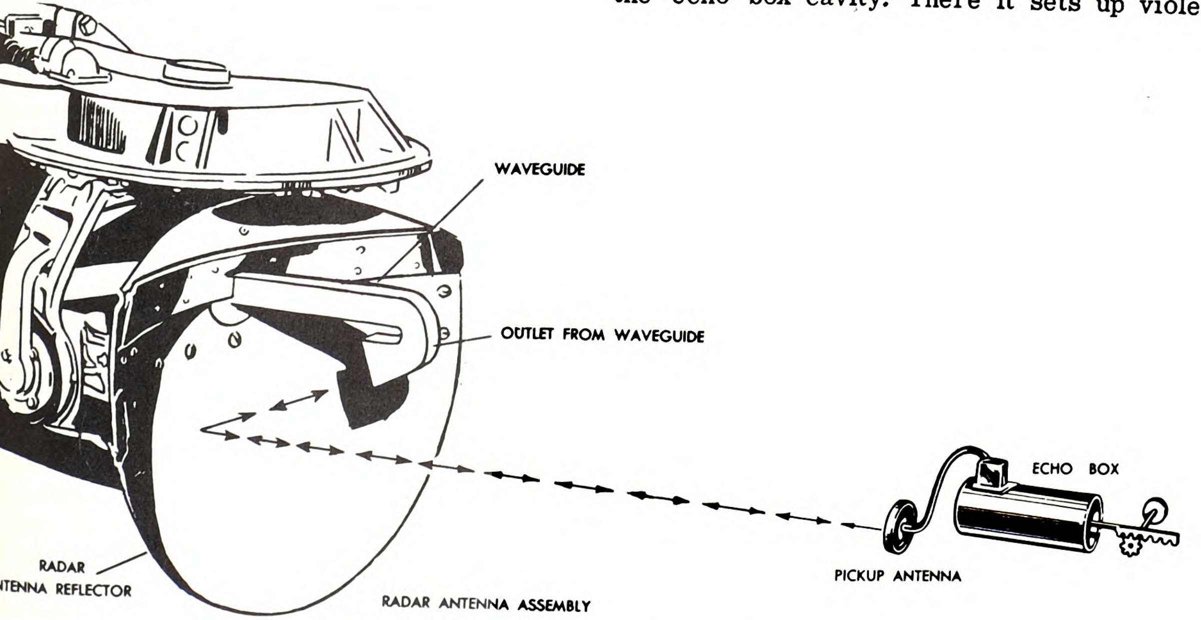

Figure 7-46.—Cavity as an echo box.

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oscillations, and the cavity itself acts like a transmitter for a period of about 20 to 40 microseconds after the pulse generated by the radar transmitter ends. (When you view the oscillations on an oscilloscope, their waveshapes appear as shown in figure 7-47.) The energy which the echo box radiates is picked up by the small pickup antenna located in front of the radar antenna assembly and fed into the radar receiver. The receiver displays it on the indicator screen. Since this signal simulates a radar echo, the cavity which transmitted it is appropriately called an ECHO BOX. It is thus a means of supplying a signal for tuning the receiver. The echo box may also be connected directly into the waveguide's directional coupler. Measurement of "ring time" will give a rough indication of radar system performance.

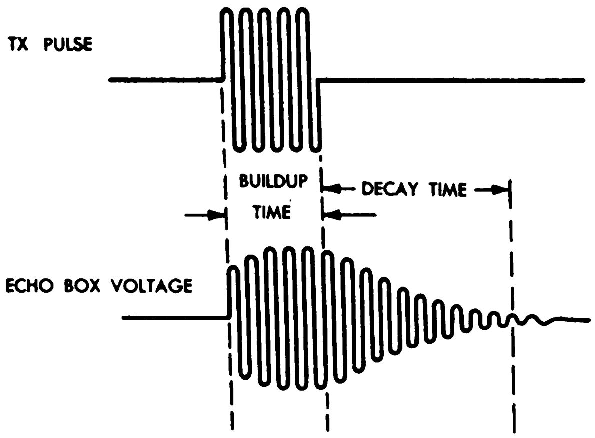


Figure 7-47.—Oscillations in echo box.

DUPLEXER SYSTEMS

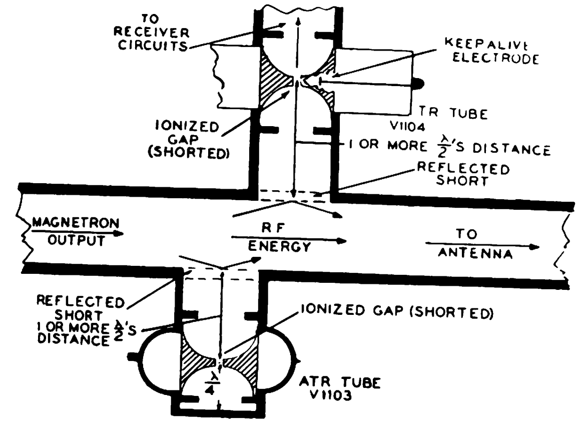
Basic Systems

In present-day aviation radar it is desirable to use a single antenna for both transmitting and receiving. A fast acting electronic switching device is required to disconnect the receiver from the transmission line during periods of transmission and to disconnect the magnetron during periods of reception. The receiver must be disconnected in order to protect the receiver input section and crystal since the magnetron output may be several megawatts. This function is performed by the TR tube. The magnetron must be disconnected during periods of reception in order to allow all available reflected energy from the target to pass to the receiver. This function is performed by the ATR tube.

The device used to perform this switching is known as a DUPLEXER. In performing this action the duplexer makes use of one or more gas-filled tubes known as transmit-receive (TR) tubes. These tubes are a spark gap enclosed in a gas-filled envelope. They are practical for this function because of the tremendous power difference between the transmitted and received signal. Ionization occurs during the transmitter pulse period and causes the tube to function as a short circuit or closed switch. During the reception period these tubes remain de-ionized because the received signals are low power; thus they appear as an open circuit.

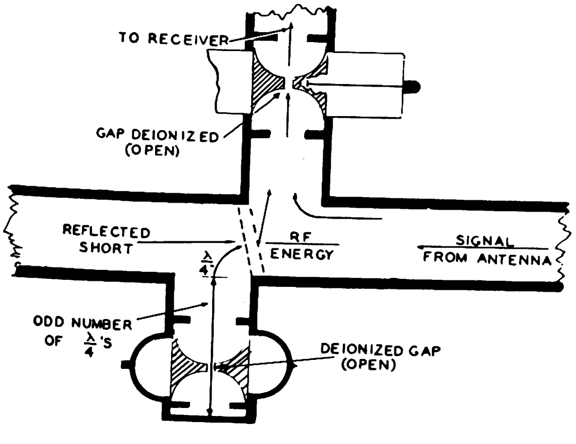
A simplified cross-section view of a waveguide system duplexer is shown in figure 7-48. The TR tube (V1104) is used to protect the crystal mixer and the receiver circuits during transmission. When the magnetron fires, sufficient voltage is impressed on the TR tube to ionize it completely and break down the gap, producing an effective short circuit. Since the TR tube is placed a number of half wavelengths from the waveguide, a short circuit existing within the tube reflects an effective short circuit at the entrance of the receiver T-junction. This prevents the RF pulse from reaching the crystal and the receiver, but permits it to flow freely to the antenna. The operation of the duplexer during transmission is shown in figure 7-48 (A). After the pulse has passed, the tube de-ionizes and again presents a high impedance at the entrance of the receiver T-junction. This allows any reflected signals to reach the crystal mixer. Duplexer action during signal reception is shown in (B) of the same figure.

The ATR tube (V1103) is located a number of half wavelengths from the waveguide; thus when the transmitter fires, which breaks down the gap of the ATR tube, an effective short circuit is reflected across the opening at this T-junction. This causes the wall to appear continuous to the transmitted energy; thus the energy passes unimpeded. The ATR waveguide section is so constructed that an odd number of quarter wavelengths exists between its shorted end and the opening to the waveguide. During signal reception, the ATR tube is de-ionized and causes an effective open circuit to appear at the opening of the ATR junction. This causes a reflected short across the waveguide adjacent to the TR opening, as illustrated in figure



TRANSMISSION OF PULSE

(A)



SIGNAL RECEPTION

(B)

Figure 7-48.—Duplexer action in a waveguide.

-48 (B). The received signal is guided into the R cavity instead of continuing to the mag- etron.

Notice that both TR's in this illustration re in the narrow section of the waveguide, thus ney are an E-type junction whereas the applica- on of an ATR, previously explained in this hapter under the heading "T-junction," was n H-type.

Characteristics of TR Tubes

At sea-level pressure approximately 30,000 lts is required to break down a spark gap of e inch. Approximately 50 volts is required to aintain ionization; this is known as running-voltage. Once the voltage has been removed a lapse of approximately 10μsec. is required for de-ionization. By enclosing the spark gap in a partially evacuated envelope, the breakdown voltage will be reduced as well as the running-voltage and the de-ionization time.

Figure 7-49 shows the voltage envelope that appears across the TR spark gap and the receiver input when the transmitter fires. For efficient transmitter operation it is important that the power dissipated by the TR tubes is small as compared to transmitter power. Also the TR tubes must maintain a properly matched line while they are fired. During the time that the transmitter is fired the TR tubes must afford sufficient attenuation to prevent the power that leaks into the receiver from being of so great an amplitude that it may damage the receiver crystal. To allow scope presentation of nearby targets it is necessary that the TR tubes de-ionize rapidly.

The amplitude and duration of the ignition spike must be reduced to the extent that the receiver crystal will not be damaged. This is accomplished by providing a keep-alive voltage to the TR tubes. TR tubes that perform this function contain three electrodes, two of which provide the main gap which does the switching, and the third, called the keep-alive electrode. This keep-alive electrode is mounted close to one of the other electrodes. It is connected to a relatively high direct negative potential which causes steady partial ionization of the gas between it and the main electrode. This insures almost instantaneous firing of the TR tube for each pulse of the magnetron.

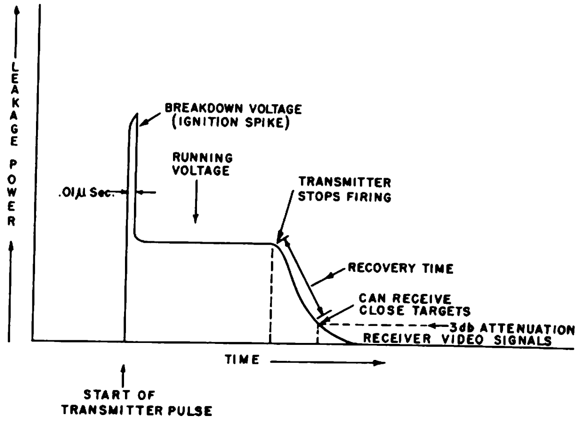


Figure 7-49.—Voltage envelope seen across the TR spark gap when the transmitter is fired.

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A CRYSTAL SHUTTER is frequently used as a protective device for the receiver crystal while the radar is turned off. When the radar is off no keep-alive voltage is applied to the TR tube; thus there is the possibility that energy radiated from nearby radars may damage the crystal. A typical crystal shutter assembly may consist of a waveguide gate and a solenoid that controls the position of the gate. When the radar system is not in operation the solenoid is not energized and the position of the gate is such that it causes a virtual short circuit across the waveguide path to the receiver input. When the radar system is in operation, the solenoid is energized and causes the gate to move from the waveguide to a position where it will offer no interference to signals traveling to the receiver.

Protection of the receiver may be improved by installing a transformer between the waveguide and the TR tube. As a result of the step-up ratio of the transformer the voltage across the TR tube will be greater than that across the line. This increase in voltage causes the tube to ionize faster, thus more receiver protection. An added benefit of the transformer action is less transmitter power loss since there is less voltage drop across the line at the TR T-junction. Resonant transformers are used for this purpose in microwave TR systems.

The cavity of the TR tube is designed to have a high Q; this necessitates careful tuning. Tuning is accomplished by means of a tuning screw which varies the separation of the main electrodes. Some equipments use a tunable ATR tube which must also be tuned to the transmitter. A detuned TR will cause receiver sensitivity to drop. A means of determining if the TR is detuned is to compare the sensitivity of the receiver at the image frequency with the sensitivity of the receiver at the fundamental frequency. Before this comparison can be made it is necessary to know what this difference in sensitivity should be. This data may be obtained by making tests on a radar that in functioning in accordance with its specifications. The data obtained may be used for comparison reading.

RECOVERY TIME

Recovery time may be described as the time required for a TR tube to de-ionize effectively. Specifically it is the time between the end of the transmitted pulse and the time where the received signal attenuation drops to 3 db (half-power point). This recovery time may vary from approximately 1μ sec. to 36μ sec., depending upon the type of TR tube in use, its age, and the amount of transmitter power. The length of the recovery time period is determined by the length of time required for the free electrons and ions, that remain in the gas after the transmitter pulse has been removed, to recombine. A short recovery time means that target echoes will be received sooner after the transmitter pulse ends.

LIFE OF TR TUBES

The life of a TR tube is relatively short as compared with most other tubes. A major factor that shortens the life of these tubes is the gradual loss of gas pressure. This is the result of chemical combination of the gas and the tube electrodes; also molecules of gas become embedded in the electrodes as a result of glow and keep-alive discharge. One means of lengthening the life of these tubes is to maintain the keep-alive current within design limits. Some equipments provide test points for making current checks. A reading lower than the normal minimum current will most likely be an indication that the TR tube is not operating at proper efficiency.

The most general indications of defective TR tubes are as follows:

1. Receiver recovery time will increase.
2. Receiver sensitivity will decrease.
3. Receiver crystals will become defective. (This will be indicated by an increase in crystal back current.)

Some radars use the same tube for TR and ATR operation. In some cases a tube that will not operate as a TR may be used satisfactorily as an ATR; thus for emergency operation the tubes may be interchanged.

Microwave Coaxial Line Duplexer Systems

At frequencies up to approximately 3,000 megacycles coaxial lines are generally used for RF transmission. The reason for using this type line is that at these frequencies should a waveguide be used the size would be so great that it would be impractical. Figure 7-50 shows an application of a TR switch in connection with a coaxial line. The TR tube is mounted in a

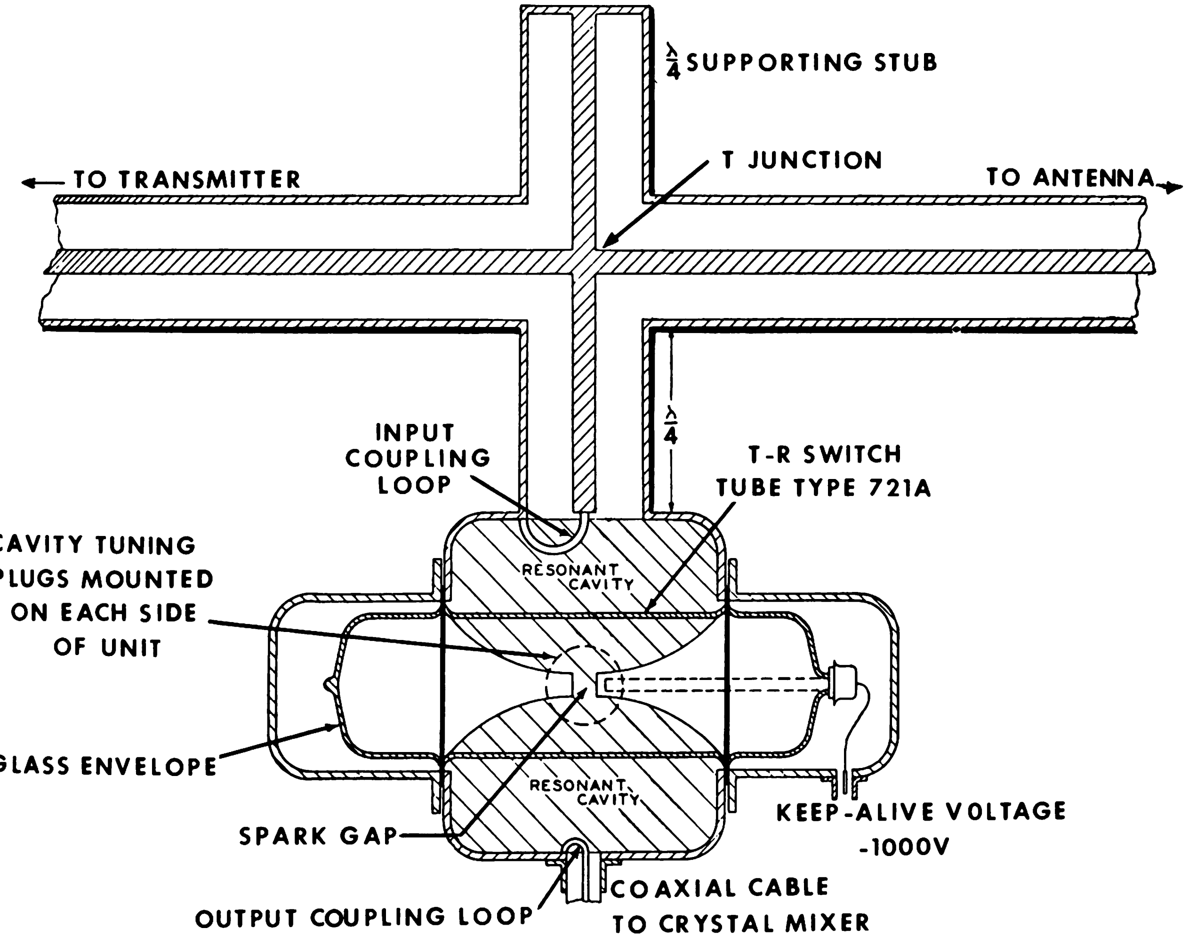

Figure 7-50.—TR switch and coaxial line.

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ndrical resonant cavity to form the TR ch. At frequencies of 3,000 mc. and higher, nant cavities are of practical size. The contains two conical electrodes which act spark gap. They are brought out through lass envelope and connected to the cylindrical mount to complete the resonant cavity (lightly shaded area).

A simplified sketch of the resonant cavity with an approximate equivalent circuit is shown in figure 7-51. The coupling loops which are used to couple RF energy into and out of the

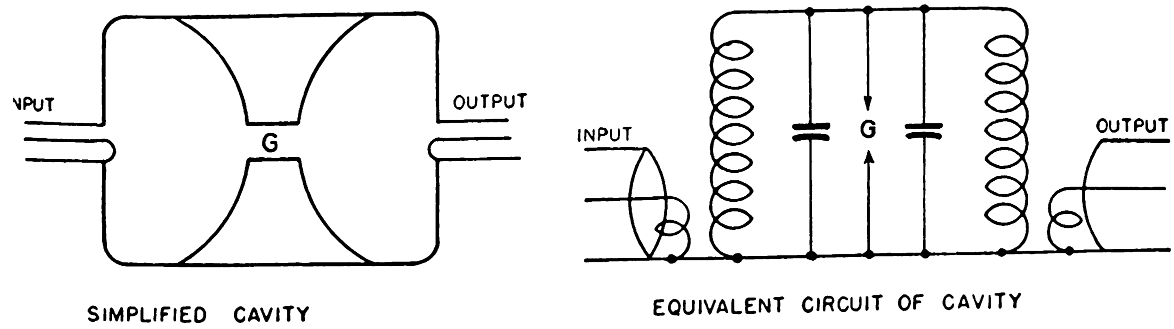

Figure 7-51.—Equivalent circuit diagram of resonant cavity.

cavity are represented as transformer windings. The resonant cavity is represented as two resonant circuits in parallel. If the gas at G does not break down, the input voltage is transformed to a high level by one tuned circuit and reduced to its original level in the secondary winding at the output. Thus the cavity acts as a highly selective transformer with a 1:1 turns ratio. If the input voltage is large enough, it is transformed to a voltage sufficient to break down the spark gap. When the gap conducts, the resonant tank is short-circuited, and a short circuit is therefore reflected into the input transformer primary.

Although this conduction does not constitute a perfect short circuit, it causes a very low impedance to appear at the input coupling loop. This very low impedance reflects to the T-junction a quarter wavelength away as a high impedance. The circuit to the receiver therefore is disconnected by the conduction of the TR switch tube.

Since the impedance across the gap is not zero during the pulse, some energy from the transmitter is coupled into the receiver. The amplitude of the voltage so coupled is reduced by the TR switch and transformer stepdown action to a value which is low enough to prevent harm to the crystal mixer. An added safeguard is the KEEP-ALIVE VOLTAGE.

High Power Waveguide Duplexers

A special problem is created by radars that produce outputs in excess of one-half megawatt (500,000 watts). A contributing factor to this problem is that the TR cavity affords little attenuation to the multiples of the carrier frequency which most magnetrons generate. The leakage power of these multiples becomes excessive in high power radars. In order to protect the receiver crystal it becomes necessary to use a modified TR system.

The method generally used to provide the necessary added protection is that of inserting a pre-TR tube at the T-junction ahead of the TR tube. When the TR tube fires, a high impedance is reflected to the input side of the pre-TR which is three-quarter wavelength from the TR tube. This high impedance causes a high voltage drop in the waveguide at this point which causes ionization across the input. This ionization permits the transmitter power to flow with negligible loss and effectively disconnects the receiver from the waveguide. During periods of reception this modified duplexer functions similarly to those previously discussed in this chapter.

Hybrid Duplexer

A type of duplexer somewhat different from those already discussed is the HYBRID RING. This duplexer is capable of performing the duties of the conventional ones already discussed, and in addition it has a low standing wave ratio and the ability to transfer high power.

The hybrid ring shown in figure 7-52 is a form of hybrid junction, which is a device that transmits power to two lines from each of two independent inputs that are not coupled together. This type of junction is frequently referred to as a "magic T." NOTE: This statement holds true for the hybrid ring duplexer only during reception; thus the magnetron is not coupled to the antenna and there is no dissipation of received power by the magnetron.

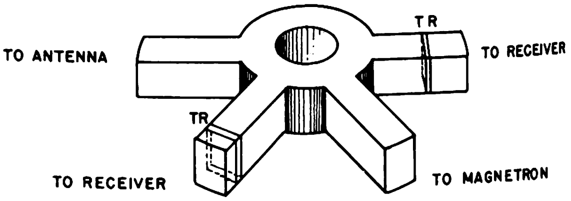

Figure 7-52.—A hybrid ring duplexer.

During the transmitter pulse the duplexer does not function as a true hybrid ring because the ionization of the TR tubes by the high power transmitter pulse serves to couple the magnetron to the antenna. The TR tubes also perform their normal protective action for the receiver crystal.

A COMPLETE WAVEGUIDE RF SYSTEM

Airborne radar equipments utilize a system of waveguides for the purpose of transmitting RF energy. A typical radar waveguide system will be discussed to enable you to understand the relationships and applications of the waveguide and its special components, which have already been presented in this chapter. A magnetron is generally used as a signal source. Since airborne equipment is flown at high altitudes, the waveguide system must be maintained t least at sea level pressure. This is to prevent rc-over which may occur at high altitude due o decreased atmospheric pressure. The change n atmospheric pressure may cause condensa-ion of moisture in the waveguide and this in urn may cause RF loss, corrosion, and increase he possibility of arc-over. Most aircraft radars se an automatic pressurization system. This ystem supplies dry air to the waveguide and in ost cases to the transmitter and modulator. he air is dried by passing it through a de-ydrator before forcing it into the system.

Figure 7-53 shows a waveguide system of airborne radar installation. The source of F energy is a magnetron which is connected to the waveguide by the flexible section of waveguide Z1305, shown in the upper right-hand corner of the figure. The mode of propagation in this guide is $TE_{1,0}$. During operation, the transmitter output in traveling through the waveguide to the antenna passes through the duplexer section. The ATR tube is located at the T-joint nearest the transmitter. The TR tube is located at the second T-connection from the transmitter. In addition to its function as a TR it also provides desirable frequency discrimination and image rejection since it is tuned to the transmitter frequency. Since the TR cavity is tuned to resonate at the transmitter frequency for search radar reception, it presents a bad

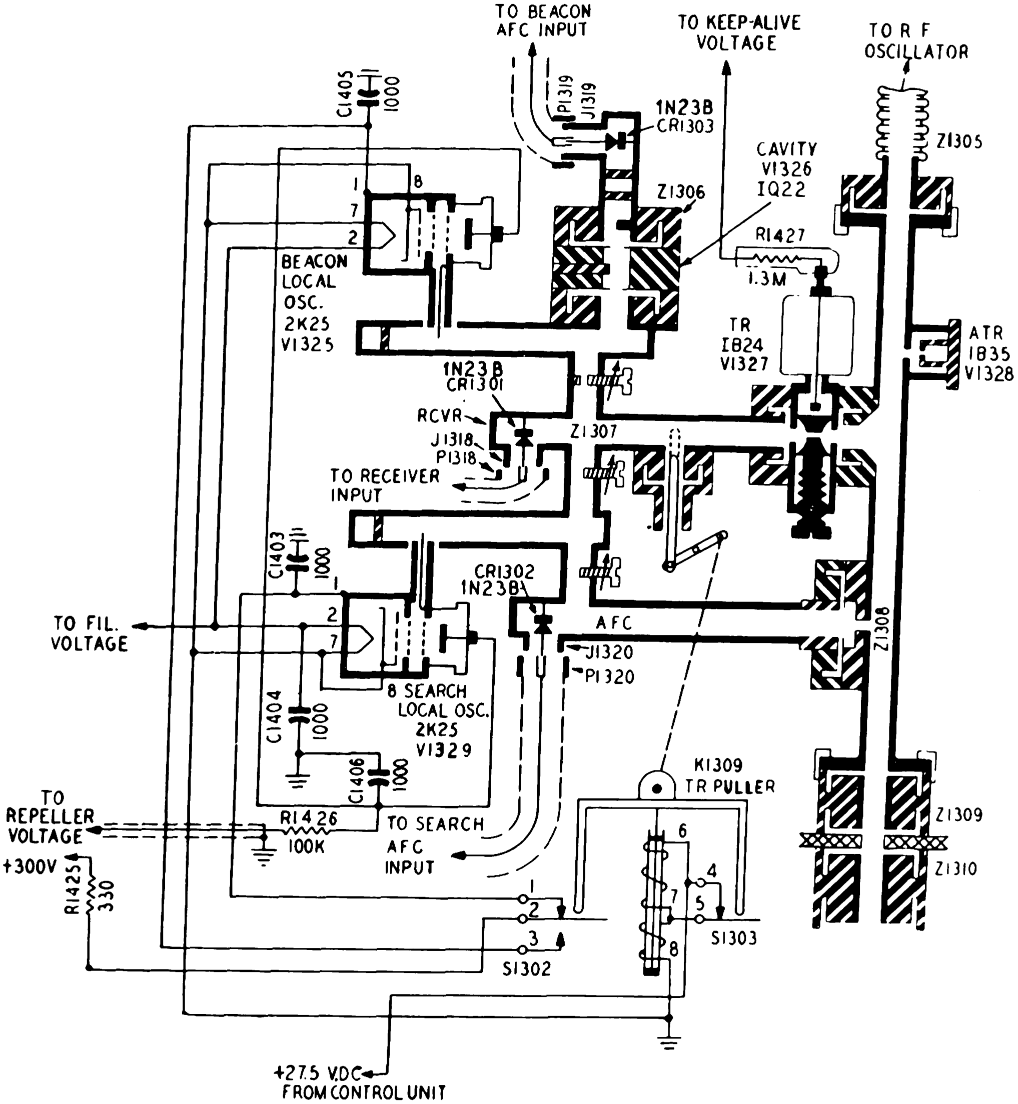

Figure 7-53.—Mixer, duplexer, local oscillators, and associated plumbing.

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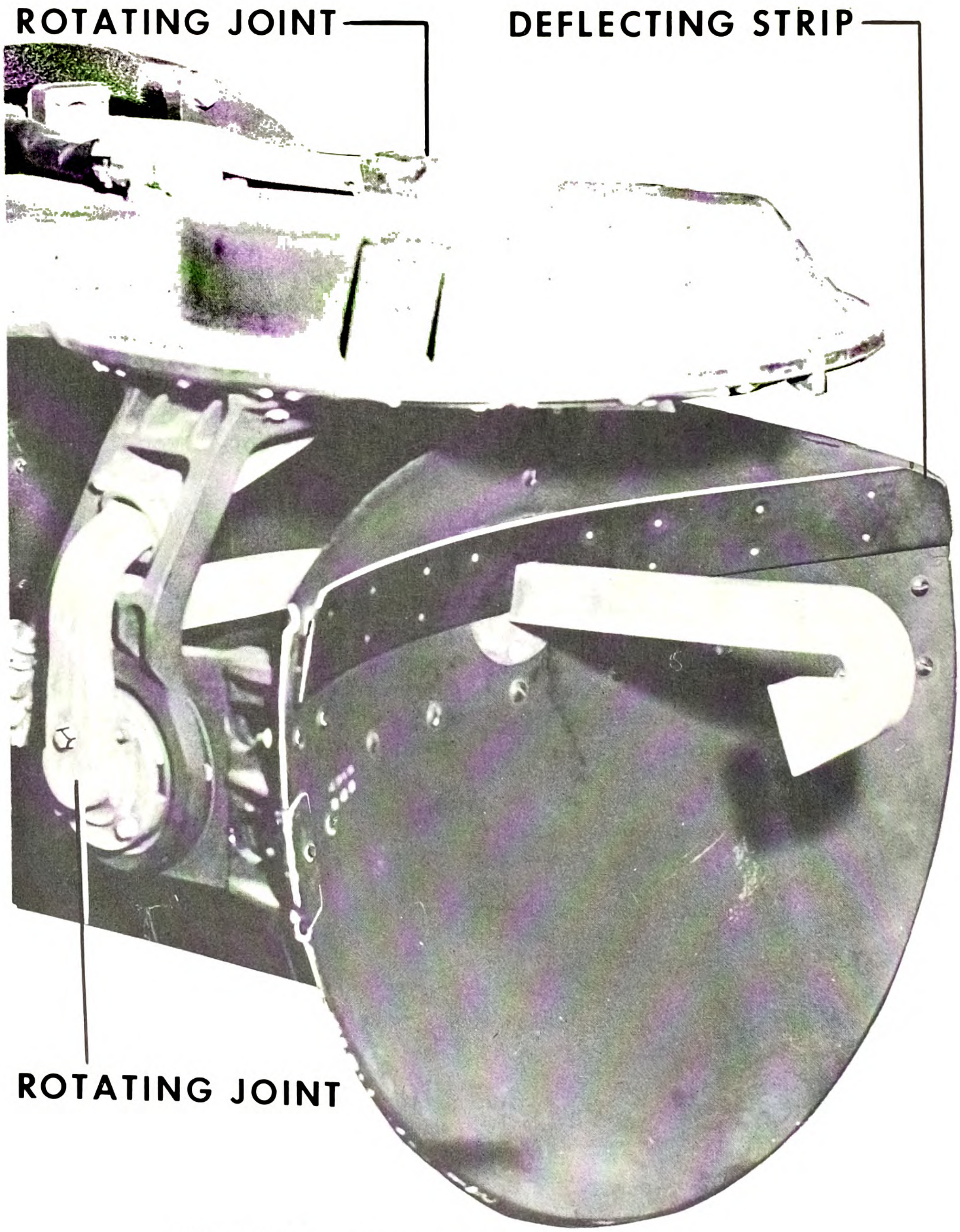

Figure 7-54.—A complete radar antenna assembly.

match for beacon signals. However, during beacon operation the TR puller relay is energized and inserts a plunger into the receiver section of the duplexer. This plunger is adjusted to resonate the TR cavity to the beacon transmitter frequency during beacon operation. Note that a keep-alive voltage is applied to the TR tube and that the series resistor R1427 is placed near the TR tube to prevent oscillation.

Located at the third T-junction is the AFC coupling. This junction provides a means of obtaining a portion of the transmitter output for

AFC operation. The remainder of the waveguide ssembly is known as a mixer and consists of a ectangular block containing four chambers. These are interconnected through narrow penings. The amount of coupling can be adusted by means of screws (waveguide atenuators) which project into the openings. The our chambers are:

Search local-oscillator.
Beacon local-oscillator.
Receiver-mixer and TR.
Automatic frequency control.

The flow of energy is continuous through the ain guide to the antenna. Each section of the ide is connected to the next with a choke joint. section of waveguide containing a directional upler is normally connected in series with e waveguide between the duplexer and the tenna assembly. A section of flexible waveide will most likely be used between the plexer and the antenna. This serves to insulate the units from mechanical vibrations of the aircraft by providing a flexible connection between shock mounted components.

The antenna shown in figure 7-54 is designed to rotate horizontally and to tilt vertically. Thus, the signal must pass through the two rotating joints before reaching the antenna proper. The radiating system consists of a horn type radiator and a parabolic reflector with a narrow deflecting strip, designed to produce the desired beam (cosecant-squared) pattern. The energy is directed by the horn into the modified parabolic surface from which it is projected forward as a vertical, fan-shaped beam.

The energy that returns from the target is gathered by the reflector and concentrated at the horn. It passes from the horn into the waveguide, travels toward the magnetron, and is stopped at the ATR box. It is then reflected back along the guide to the mixing chamber.

QUIZ

As the frequency in a waveguide is increased, the effective transmission line
- a. becomes wider
- b. becomes narrower
- c. does not change
- d. shorts the energy to ground

A disadvantage of the two-wire transmission line, as compared with a waveguide, is the
- a. larger size required
- b. higher radiation losses
- c. lower radiation from the line
- d. lower breakdown voltage

The velocity of propagation of RF energy in a waveguide is
- a. greater than the free space velocity
- b. less than the free space velocity
- c. equal to the free space velocity
- d. greater than the velocity of light

hat mode of operation is used in a waveuide acting as a rotating joint?
- a. $TM_{1,1}$
- b. $TE_{1,1}$
- c. $TE_{0,1}$
- d. $TM_{0,1}$

5. One function of the TR tube is to
   - a. keep most of the RF energy from entering the radar receiver during transmit time
   - b. direct the RF energy into the transmitter section of the radar
   - c. prevent an output from the radar transmitter during the receive period
   - d. add the necessary impedance to the duplexer system during transmit time

6. Recovery time may be described as the time required for a TR tube to
   - a. become ionized
   - b. become de-ionized
   - c. reach its operating temperature
   - d. become completely cold

7. The A dimension, at frequency of cutoff, equals
   - a. one wavelength
   - b. a half wavelength
   - c. a three-quarter wavelength
   - d. a quarter wavelength

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8. An advantage of waveguide over the coaxial line is
   a. lower power-handling capability
   b. lower copper losses
   c. lower breakdown voltage
   d. greater heating of the dielectric

9. The main function of the ATR tube is to
   a. prevent RF energy from leaving the transmitter during transmit time
   b. prevent received RF energy from getting back into the transmitter section
   c. compensate for all losses within the duplexer section
   d. trigger the transmitter at the proper time

10. In high-power type duplexer systems, a device used to prevent excessive power leakage to the radar receiver during transmit time is called a
   a. cavity attenuator
   b. pre-TR tube
   c. ATR tube
   d. silicon crystal

11. A disadvantage of a waveguide at low frequencies is
   a. lower efficiency
   b. the large size requirement
   c. lower power-handling capability
   d. greater radiation losses

12. When plugs are inserted in the cylindrical side of a cavity, the deeper the plug extends into the cavity, the
   a. higher the frequency
   b. lower the frequency
   c. smaller the magnetic field strength
   d. smaller the electrostatic field strength

13. The B dimension mainly determines the
   a. frequency of cutoff
   b. mode of operation
   c. power-handling capability
   d. size of the A dimension

14. To exist in a waveguide, the H-lines must
   a. be parallel to the E-lines
   b. be perpendicular to the B dimension
   c. be perpendicular to the A dimension
   d. form complete loops

15. When a probe is used to excite a waveguide, it sets up
   a. electrostatic fields
   b. electromagnetic fields only
   c. magnetic fields only
   d. electrostatic and magnetic fields

16. A keep-alive voltage is applied to the
   a. pre-TR tube
   b. ATR tube
   c. TR and ATR tubes
   d. TR tube

17. In a properly operating duplexer system, during transmit time, the ATR tube
   a. and the TR tube are in an unfired state
   b. is unfired and the TR tube is fired
   c. is fired and the TR tube is fired
   d. is fired and the TR tube is unfired

18. What is the wavelength required to make a 90-degree bend so as to avoid reflections?
   a. Greater than 3 wavelengths
   b. Less than 2 wavelengths
   c. Greater than 2 wavelengths
   d. Less than 3 wavelengths

CHAPTER 8

UHF AND MICROWAVE TECHNIQUES

The purpose of this chapter is to acquaint
ou with oscillators and oscillatory circuits em-
loyed at UHF and microwave frequencies.
lso, information dealing with the pulsing tech-
iques used in RF generators of this frequency
ill be presented. Specifically, it discusses
roblems involved in generating high-frequency
gnals, explains the theory and operation of a
umber of oscillators employed at these fre-
uencies, and describes various methods for
lsing oscillators.

ADVANTAGES OF HIGH FREQUENCIES

Perhaps the main reason for using higher
equencies is that it is possible to construct
ective antennas of smaller size than when
ver frequencies are used. Small directive
ennas are an important consideration in air-
ne equipment where space and weight are
jor problems.

Aside from the factors of size and weight,
se frequencies are highly applicable to radar
ipment for they produce better target echoes
make possible the detection of smaller tar-
s. The size of the target that radar can detect
ends mostly on the frequency. In general the
er the frequency, the smaller the target that
radar can detect. A target gives the best
oes when its size is about a half wave or some
tiple of the radar frequency being trans-
ed. If the target is much smaller than a
wave, the intensity of pulse that it reflects
ow. However, as the operating frequency is
eased, the half wave becomes smaller in
th and makes it possible to detect smaller
ets.

n overall statement as to an advantage of
frequencies is that the trend toward mini-
zation becomes a reality. This is highly
able for aviation equipment. Circuit com-
nts generally become smaller as the fre-
y increases.

FREQUENCY LIMITATIONS OF CONVENTIONAL OSCILLATORS

The principal factors which limit the frequency of the ordinary type oscillator are the construction of the tube and the external circuits which connect to the tube.

Tube Construction and Limitations

The tube construction factors which limit the operating frequency of the conventional oscillator are the interelectrode capacitances in the tube, the inductances of the leads, and the transit time.

INTERELECTRODE CAPACITANCES

At low or medium radiofrequencies the interelectrode capacitances in an ordinary vacuum tube have reactances which are so large that they do not cause any serious trouble. However, as frequencies increase, the reactance of these capacitances become small enough to materially affect the performance of a circuit. A 1 $\mu\mu$f. capacitor, for example, has a reactance of 1,590 ohms at 100 mc. If this capacitor is the grid-to-plate capacitance and the RF voltage between these electrodes is 500 volts, there will be an interelectrode capacitance current flow of 500/1,590 or 0.314 amperes, an amount of current which will disturb circuit operation. On the other hand, at 1 mc. the reactance of this capacitor becomes approximately 159,000 ohms and the current flow is only 500/159,000 or 3.14 milliamperes, an amount which will not seriously affect circuit performance.

A good point to remember is that the higher the frequency or the larger the interelectrode capacitance, the higher the current flow through this capacitance. In most UHF oscillators employing ordinary tubes, interelectrode capacitance currents are much greater than the power currents supplied by the tube. These higher

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currents cause power losses in the resistance in the oscillatory circuit.

Since interelectrode capacitances are effectively in parallel with the tuned circuit, they affect the frequency at which the tuned circuit resonates. As you can see in the circuit illustrated in figure 8-1, the plate-to-cathode capacitance is in parallel with the series combination of the plate-to-grid capacitance and the grid-to-cathode capacitance. All these capacitances together form a part of the total capacitance of the plate's tuned circuit. You can find their total capacitance by the formula,

$$C_t = C + C_{pk} + \frac{C_{gk} C_{gp}}{C_{gk} + C_{gp}}$$

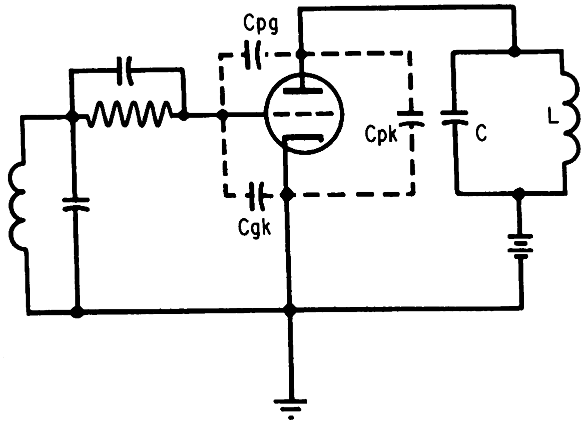

Figure 8-1.—Effect of interelectrode capacitance on frequency of tuned-plate tuned-grid oscillator.

Not only does interelectrode capacitance limit the frequency by establishing a minimum value below which it is impossible to go, but it also varies with the applied voltages and with the loading of the oscillator. This causes frequency instability, particularly when the interelectrode capacitance forms a large part of the tuning capacitance.

INDUCTANCE OF LEADS

Another frequency limiting factor with a tube is the inductance of the leads to each tube element. While these inductances do not necessarily impair the efficiency of the oscillator, they may represent a major portion of the inductance of the tuned circuit and limit the frequency by setting a minimum limit on the inductance. Furthermore, since the cathode lead is frequently common to both plate and grid circuits, feedback takes place through it and produces an additional loss of efficiency.

TRANSIT TIME

A third limitation imposed by tube construction is TRANSIT TIME. Transit time is the time required for electrons to travel from cathode to plate. At low radiofrequencies transit time is negligible, since it occupies only a comparatively small portion of an oscillatory period. But as the frequency becomes higher, transit time occupies an appreciable portion of this period and produces undesirable effects in tube operation. The effect of transit time is of special concern in connection with the input impedance of the tube. Part of the current that flows in the grid circuit is the current which charges the grid-to-plate capacitance, C_{gp}. The voltage that produces this current is the vector sum of the input voltage (grid to cathode) and the output voltage across the plate load.

At lower frequencies with a resistive load, these two voltages are 180 degrees out of phase and add algebraically to determine the charging current. This current is 90 degrees out of phase with the input voltage. However, at higher frequencies, where transit time is an important factor, the plate current begins to lag the input voltage. This causes the plate voltage to be less than 180 degrees out of phase with the input voltage, and the voltage across the capacitor to lag the input voltage slightly. As a result, the charging current will no longer be 90 degrees out of phase but will have an in-phase component. This means that power is consumed in the grid circuit. This consumption of power is effectively the same as adding a high resistance between the grid and cathode. This resistance decreases as the frequency increases.

OVERCOMING TUBE LIMITATIONS

There are several ways to reduce the effect of interelectrode capacitances in vacuum tubes. None are completely satisfactory. One is to move the electrodes farther apart. However, this is hardly desirable for it increases the transit time. Another method is to reduce the size of the tube and electrodes. This is satisfactory except for one ill effect. It decreases the power handling ability of the tube directly with the square of the factor by which the electrodes are reduced. Another method is to separate the leads and to bring them out of the envelope at the nearest point. This results in a slight decrease n the capacitances.

Similarly there are several ways to reduce he inductances of the leads. As just mentioned, ringing out electrode leads through the envelope t the nearest point produces a slight decrease n the electrode capacitance in a tube. This also ecreases the inductances of the leads. Another ethod is to make double connections to the lectrode. This makes two parallel inductances hich cut the lead inductance in half. Another ethod is to arrange the leads as extensions of e external transmission lines which are the sonant elements of the circuit. Thus the in- relectrode capacitances and lead inductances e incorporated as part of the tuned circuit. ee fig. 8-9.)

It is possible to minimize the inefficiency eviously mentioned by using a tube that has o separate external cathode connections. When e cathode lead is used for the grid return and other for the plate circuit, the unwanted dback is prevented, since the grid and plate rents do not flow in a common lead induct- e. (The 6AG5 and 6AK5, as well as many er tubes, are constructed in this manner.)

For reducing transit time, closer spacing of electrodes and higher plate voltage are em- yed. Closer spacing of electrodes, however, ses higher interelectrode capacitances. refore, it can be used only when the elec- les are made smaller. For this reason UHF illators operate at very high plate voltage. fact that a radar and other pulsed trans- ers do not operate continuously is an ad- age in that high enough voltages may be l to reduce transit time without exceeding maximum power rating of the tube. Oper- g with high voltage does, however, neces- e some precautionary measures, such as rating the leads to avoid the presence of ssive voltage gradients in or on the surface e glass envelope, and avoiding sharp pro- ons on the high-voltage leads or electrodes event arcing.

Limitations Due to External Circuits

creases in frequency cause a rather rapid ase in the power losses in the external oscillatory circuit. These power losses are due principally to skin effect and radiation.

SKIN EFFECT

Skin effect is the characteristic of conductors at radiofrequencies in which most of the current flows near the surface of the conductor. The depth below the surface where the density of current flow is reduced to 36.8 percent of the surface value (in a copper conductor) is equal to 6.62 divided by the square root of the frequency in cycles. (This will be the depth in centimeters.) For example, this depth would be 0.0066 cm. for one megacycle and 0.00066 cm. for 100 megacycles; thus, the depth at 100 megacycles is one-tenth as great as at one megacycle.

Skin effect causes a considerable increase in the resistance in a vacuum tube circuit. This results in a lower Q and increased I^2R losses. To prevent skin effect losses, conductors are made large in size and tubular in shape since current flows only in the surface at UHF frequencies. In addition they are plated with silver, since it has a higher conductivity than copper. At UHF frequencies most and possibly all current flow will be in the silver plating.

RADIATION

Radiation, the other cause of power loss, is due to incomplete cancellation of electromagnetic fields in the region surrounding the circuit. When the frequency is low enough so that the spacing between two parallel conductors equals only a very small fraction of a half wavelength, there is almost complete cancellation of fields in all directions. At higher frequencies, however, the same spacing would represent a larger fraction of a half wavelength. This means less cancellation. In extreme cases, such as where the spacing is a half wavelength, the fields add in the direction of the plane containing the two conductors. This causes the tuned circuit to radiate energy like an antenna. Therefore, as the frequency increases, it is necessary to reduce the spacing between the parallel elements. However, there is a limit on how far you can go in reducing the spacing; too close spacing will result in arcing of the tank circuit. Another means of eliminating radiation is the use of concentric lines instead of open wire line. This eliminates radiation entirely, since the outer conductor acts like a shield which prevents the electromagnetic field from expanding into space.

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LIMIT OF INDUCTANCE AND CAPACITANCE

At UHF frequencies it is necessary that the inductances and capacitances in the oscillatory circuit be very small. The lower limit of capacitance is the sum of the interelectrode capacitances and the distributed capacitance of the leads. The lower limit of inductance is the lead inductance plus the inductance necessary to connect the tube electrodes externally. UHF oscillators approach both these limits, the only capacitance in the tank circuit often being a small trimmer capacitor for fine tuning adjustments, and the inductance often being the shortcircuited transmission line less than one-quarter wavelength in length. In the typical parallel line tank circuit (fig. 8-2), the expression for the input (sending end) reactance X_s (looking at the circuit from the tube) of the tank circuit is

$$X_s = Z_o \tan B_s$$

where Z_o is the characteristic impedance of the line and B_s the electrical length.

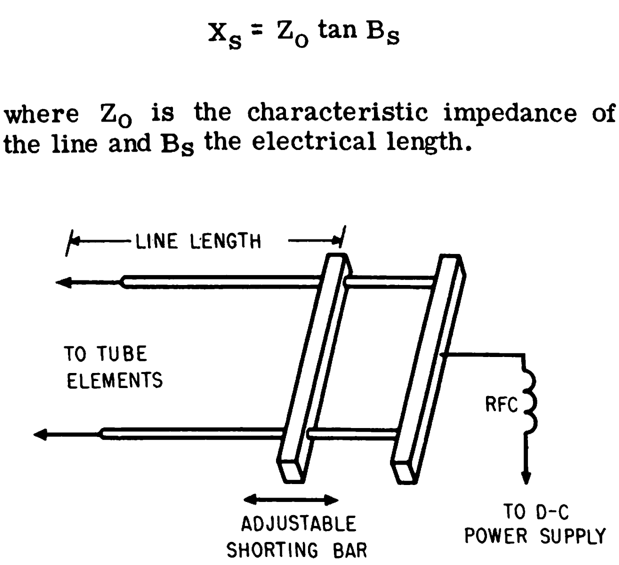

Figure 8-2.—Parallel wire resonant circuit.

As you can see in the expression, if B_s is less than 90 degrees ($\lambda/4$), then tan B_s is positive and the reactance is inductive. For smaller values of inductance, the length of the line is decreased. Further, this expression is true only when the resistance losses are low enough to be neglected. Frequently the tank circuit is located near a flat surface and parallel to it. The flat surface acts as a shield and, while it does not affect the electrical length of the line, it does lower the characteristic resistance of the line.

TRIODE OSCILLATORS

Ultraudion Oscillator

The typical ultraudion oscillator illustrated in figure 8-3 is sometimes used as a local oscillator in receivers and occasionally as a transmitter. The d-c circuits contain the components R_p, C_g, R_g, and the small d-c resistances in the tank circuit and leads. The components C_g and R_g form the grid leak bias circuit. The charge built up on C_g biases the tube to class C operation.

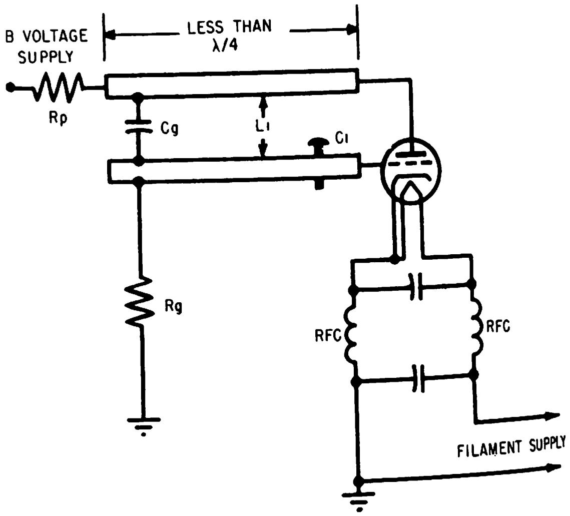

Figure 8-3.—Ultraudion oscillator.

To understand the operation of the ultraudion oscillator, consider its equivalent circuits shown in figure 8-4. So far as RF is concerned, as you can see in the equivalent circuit, the chokes in the cathode are open circuits. The tank circuit inductance L consists of the plate and grid lead inductances connected in series with the parallel combination of L_1 and C_1.

The simplified equivalent circuit shows that this tank circuit inductance forms a resonant circuit with the combined interelectrode capacitance, C, which is given by the equation

$$C = C_{gp} + \frac{C_{gk} \times C_{pk}}{C_{gk} + C_{pk}}$$

The expression for the frequency of this resonant circuit is

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

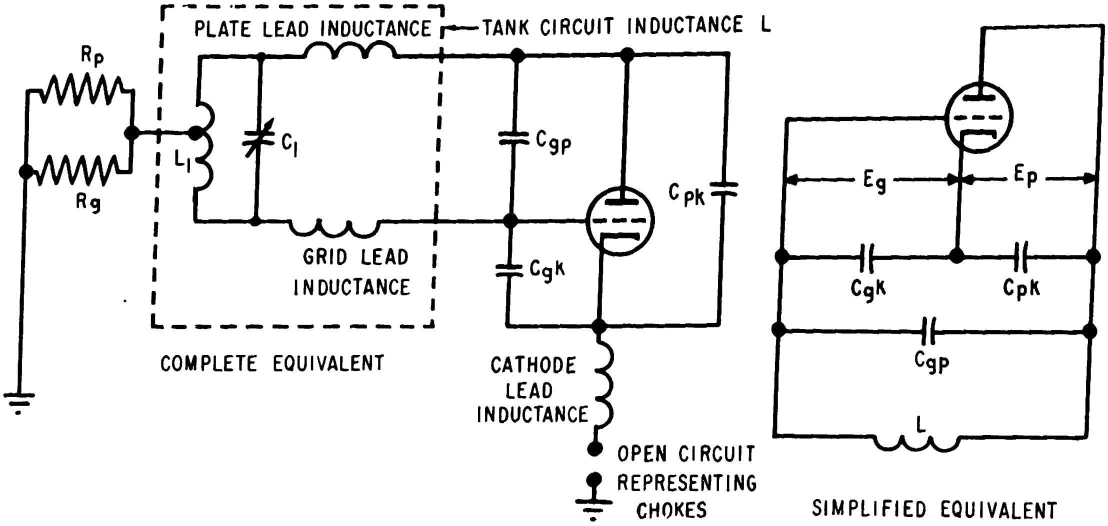

Figure 8-4.—Equivalent circuits of ultraudion oscillator for RF currents.

asically, the circuit of the ultraudion oscil- , as you can see in the simplified equiva- is that of a Colpitts oscillator. The capaci- s C_{gk} and C_{pk} form a voltage divider it. The voltage E_g developed across C_{gk} the right phase and high enough to sustain ations. The minimum amplification re- d to sustain oscillations is given by the la

$$A = \frac{C_{gk}}{C_{pk}}$$

initial gain is greater than this value, tions build up to such an amplitude that in is reduced to the value given by this a.

Lighthouse-Tube Oscillator

lighthouse-tube oscillator like the ul- n oscillator, is a single tube oscillator. It d in test equipment and low-power trans- . The lighthouse tube, which gets its rom its peculiar construction, will op- t frequencies as high as 4,000 mc. Its rid, and cathode connections are arranged it may be mounted directly in the tuning ly. (See fig. 8-5.) The component called er consists of three coaxial cylindrical ors, of which the inner cylinder makes with the plate, the next with the grid, and the outer conductor with the shell of the tube. The outer conductor provides an RF connection to the cathode through capacitance. The space between the cathode and grid conductors forms a coaxial-cathode line which in turn is shorted by means of a plunger. The insulation at the tube base between the cathode and the cathode shell (or external connection) is the dielectric between the rings which form the cathode capacitive coupling. If this capacitive coupling were not used, the grid would have a d-c path from its cylinder through the plunger and the cathode cylinder to the cathode. This capacitance in the tube base is great enough to form a virtual short circuit for RF. The d-c grid-to-cathode path consisting of R_g and C_g form the grid leak bias circuit.

In the plate circuit, the plate line consists of the grid and plate conductors. It is open circuited at the end away from the tube. The plate voltage is applied to the plate lead through the plate tuning rod at the point where the plate line is shorted. This point is one-quarter wavelength from the end. This quarter-wave section which is shorted at the point where B plus is applied presents a high impedance to RF from the open-ended plate line and therefore prevents RF from flowing into the power supply.

EQUIVALENT CIRCUITS

The equivalent circuits in figure 8-6 show the evolution of the lighthouse-tube oscillator.

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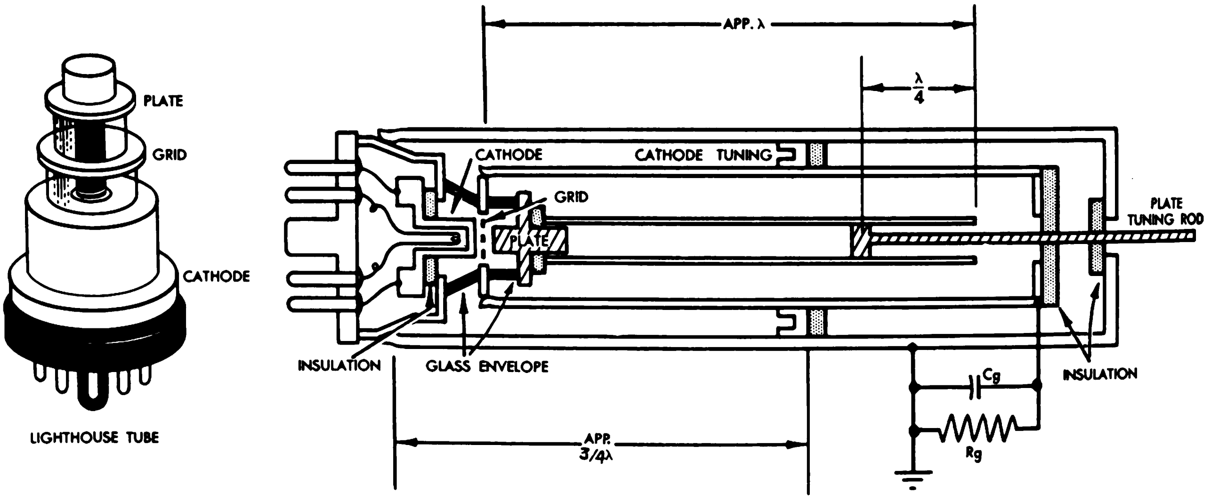

Figure 8-5.—Lighthouse-tube oscillator.

In the first equivalent, (A), the components L_k and L_p represent the inductances of the shorted cathode line and the open circuited plate line respectively. This is a true representation of the actual circuit provided that the cathode line is less than three-quarter wavelength long and provided that the plate line is less than a full wavelength long. The three-quarter wavelength and full wavelength were chosen for this circuit rather than the one-quarter and one-half wavelength due to the fact that at the frequency of operation the latter fractions of a wavelength are inconveniently short. However, keep in mind that if the cathode line is slightly less than one-quarter wavelength, it acts like an inductance; and that if the plate line is slightly less than one-half wavelength, it will act like an inductance. There is no lead inductance shown in the circuit since the lines connect directly to the electrodes. The interelectrode capacitances complete the equivalent circuit.

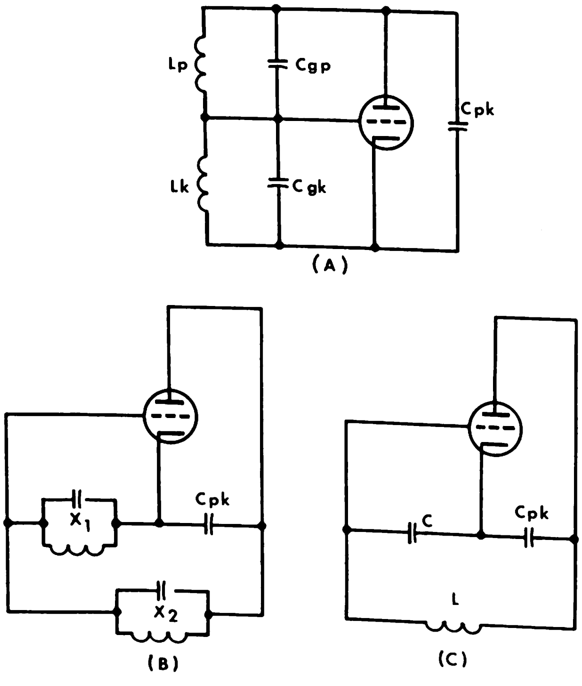

Figure 8-6.—Evolution of equivalent circuit of lighthouse-tube oscillator.

In the equivalent circuit (B), the parallel combination of L_p and C_{gp} are represented by X_2 and the parallel combination of L_k and C_{gk} by X_1. Obviously the reactances X_2 and X_1 along with C_{pk}, which you can consider unknown reactances, must form a resonant circuit. The reactance X_1 forms a voltage divider circuit along with C_{pk}. Since the voltage across X_1 is the voltage fed back to the grid, it must be 180 degrees out pf phase with the plate voltage which can happen only if X_1 is a capacitive reactance. This condition leads to the third equivalent circuit (C), in which the reactance X_1 is represented by a capacitor.

An oscillatory circuit requires at least one inductance, therefore X_2 must be an inductive reactance. Hence, in the final or the third equivalent circuit (C), the reactance X_2 is shown as the inductance L. This circuit is representative of the oscillator circuit only at the resonant frequency. On examining this circuit, tice that basically it is that of a Colpitts os- llator. Now, if X_1 is capacitive, C_{gk} must nduct more heavily than L_k; therefore the cillator frequency must be above the resonant equency of L_k and C_{gk}. Likewise, for X_2 to be ductive the oscillator frequency must be below e resonant frequency of L_p and C_{gp}. Thus you e that the oscillator frequency is between the sonant frequencies of the plate circuit and the thode circuit.

EEDBACK

In this oscillator, the amount of feedback pends upon the size of C in relation to C_{pk}. his is, in turn, a function of the tuning of the thode line; hence, the cathode tuning serves incipally for controlling the amount of feed- ck. If feedback is too small, oscillations will weak and may cease completely. If feedback too great, power consumption in the grid cir- it will become too large and will result in a crease in output of the oscillator. The value C, hence of the cathode tuning, has some effect the frequency of oscillations, but since C and ɔk are in series and C is usually much larger an C_{pk}, C must be changed considerably to fect the frequency appreciably.

ATE TUNING

Since the tuning of the plate line determines resonant frequency of the plate circuit, which turn determines the amount of inductance presented by the plate circuit at the oscillator quency, the plate tuning is the chief control the oscillator frequency. It has a secondary ect of feedback since C is determined by the ative frequencies of the cathode circuit and the oscillator. You can see from the fore- ng discussion that the plate line is tuned to the correct frequency and the cathode line djust feedback for maximum output from the illator but, since there is some interaction, ill be necessary to readjust each line for imum accuracy.

Push-Pull Oscillators

To obtain higher power outputs, two tubes in -pull circuits or four or more tubes in a oscillator are sometimes used. In push-pull uits, the tuned circuits are the parallel line her line) type. This arrangement forms a nced-to-ground system.

The oscillator circuit discussed first is the push-pull tuned-plate tuned-grid oscillator. This circuit may oscillate continuously or it may be used to provide pulsed operation; this will be explained later in this chapter.

TUNED-PLATE TUNED-GRID OSCILLATOR

In the tuned-plate tuned-grid oscillator, both the plate and grid lines are slightly under λ/4 in length. They are indicated in the circuit of the tuned-plate tuned-grid oscillator (fig. 8-7) as inductances L_p and L_g. The length of the plate line in the circuit may be varied by the shorting bar. While the grid line is of fixed length in this particular arrangement, a little greater flexibility would result if it too were adjustable in length. The inductances L and capacitors C_1, C_2, C_3, and C_4 in the cathode circuits form filters to prevent RF from reaching the filament transformer. The grid leak bias

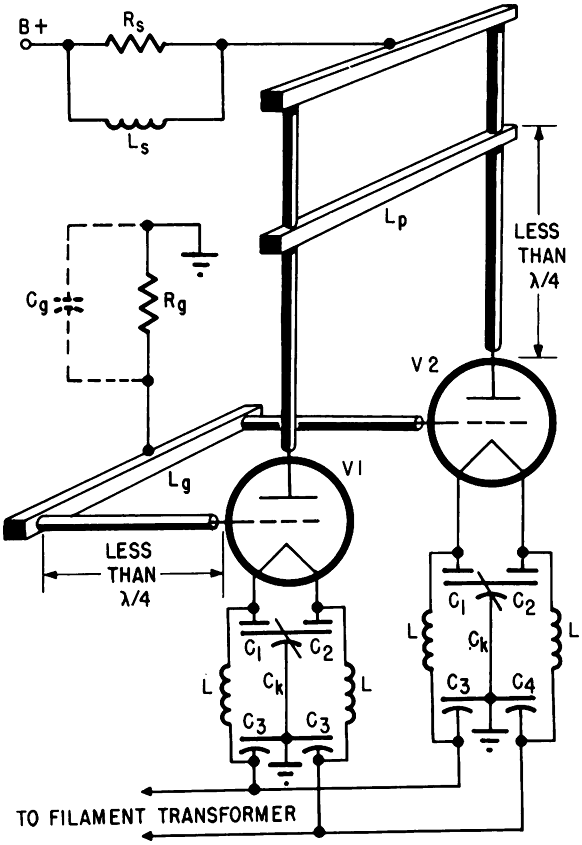

Figure 8-7.—Tuned-plate tuned-grid oscillator using Lecher lines as tuned circuits.

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developed includes R_g and C_g. The component C_g is shown as a dotted portion since it is actually the distributed capacity of the grid line to ground. B-plus voltage is applied to the plate lines through R_s and L_s. A double purpose is served by L_s: First, it prevents RF from getting into the power supply; and second, it suppresses parasitic oscillations.

EQUIVALENT CIRCUITS

In equivalent circuit (A), figure 8-8, both tubes of the oscillator are shown. L_p is the inductance, which represents both the plate line and the plate lead inductances. L_g represents the inductance of the grid line and grid leads. L_k is the cathode lead inductance. With proper adjustment of C_k, L_k forms a series resonant circuit that effectively grounds the cathode within the tube.

The second equivalent circuit (B) shows only one tube since both circuits are identical. L_{pk} is one-half L_p and, along with C_{pk}, forms a circuit that resonates at a frequency above that at which the entire circuit oscillates. Likewise L_{gk}, which is one-half of L_g, resonates with C_{gk} at a higher frequency than the oscillator frequency.

In the third equivalent circuit (C), both of the parallel circuits of (B) are represented by inductors. Since both of the parallel circuits are resonant at a frequency higher than the overall

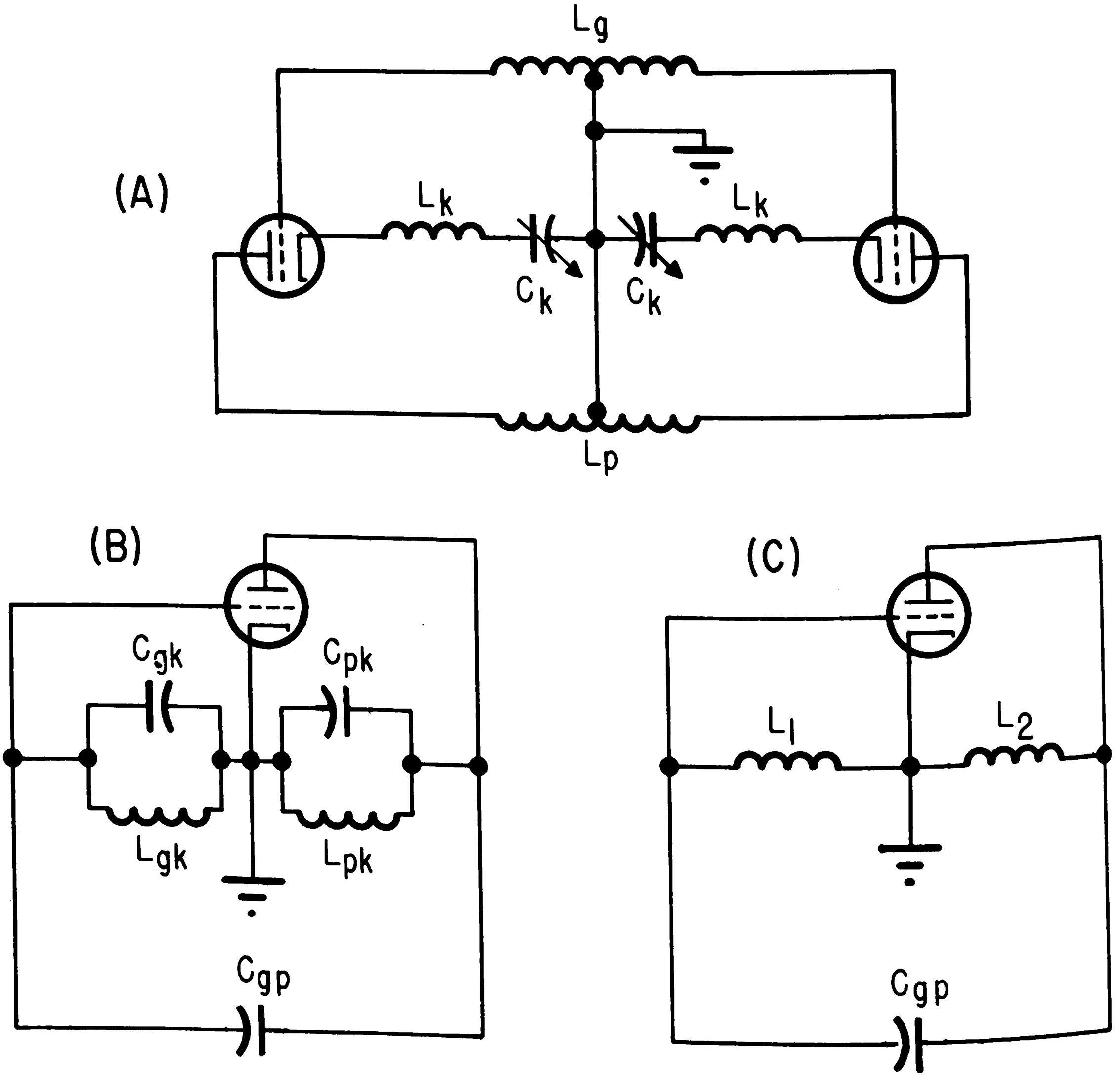
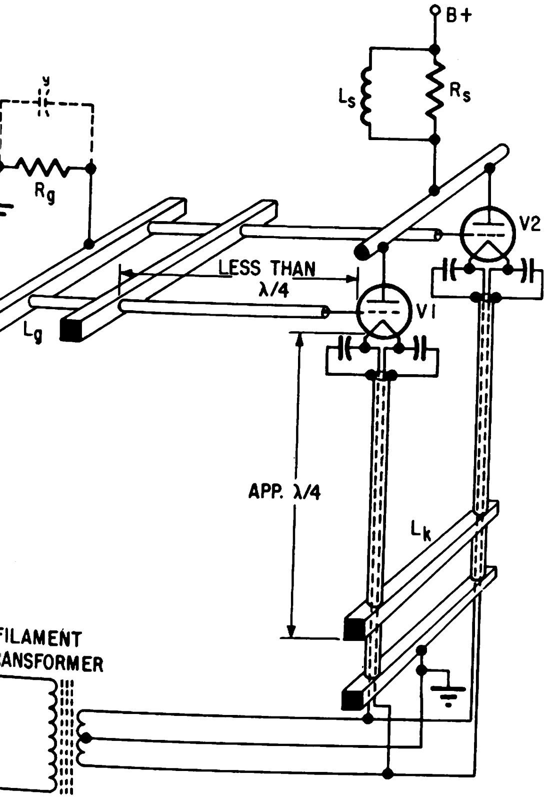


Figure 8-8.—Equivalent circuits of TPTG oscillator.

cillator frequency, they appear inductive. In s equivalent circuit the oscillator is the rtley type. The oscillator frequency must be ver than either the plate or grid resonant quencies. The circuit that is lower in frency (plate or grid) controls the oscillator quency, and the other controls the amount of dback.

NED-GRID TUNED-CATHODE CILLATOR

Another push-pull oscillator circuit which is d in a number of types of UHF equipments is tuned-grid tuned-cathode circuit (fig. 8-9).



igure 8-9.—Tuned-grid tuned-cathode oscillator.

s oscillator, the plates are effectively circuited by tubes which have very little ead inductance and which are connected ection of line. When the lead inductance is enough to become objectionable, the plates nnected by means of a half-wave section to insure a short circuit. The d-c circuits are the same as in the tuned-plate tuned-grid oscillator.

Equivalent Circuits

In the first equivalent circuit (A), figure 8-10, both tubes are shown. The grid line is represented as inductance L_g, the cathode line as reactance X_k, and the interelectrode capacitances as indicated.

Circuit (B) shows only one tube. In this circuit L_{gp} represents one-half of L_g and X_{pk} represents one-half of X_k. By following the line of reasoning similar to that used in the TPTG circuit, you see that the parallel combination of X_{pk} and C_{pk} must be capacitive at the oscillator frequency. Thus it is shown as capacitor C_k in the third equivalent circuit (C).

The oscillator must have an inductive element; hence L_{gp} and C_{gp} in parallel act like an inductance L as shown in (C). For L_{gp} and C_{gp} to be inductive, the grid line must always be less than $\lambda/4$ in length. Since variations in L have the greatest effect on the frequency of oscillations, THE GRID LINE IS THE PRIMARY FREQUENCY TUNING DEVICE. The cathode

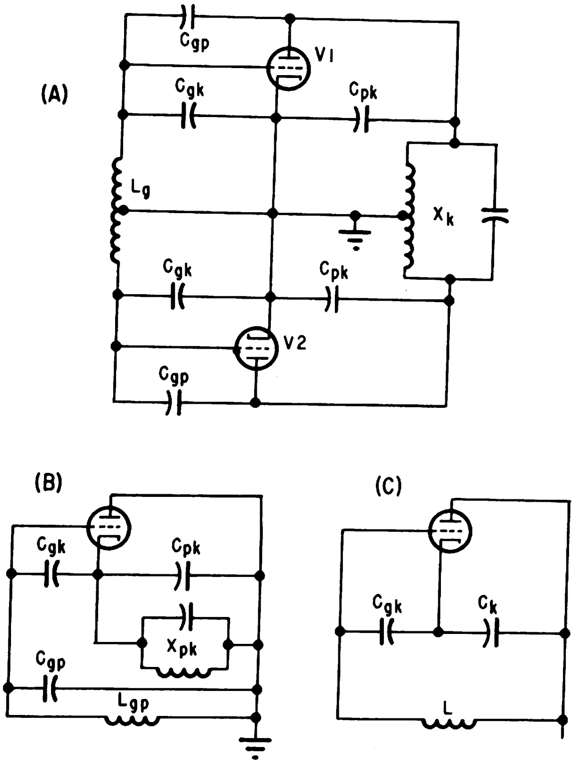


Figure 8-10.—Equivalent circuits of tuned-grid tuned-cathode oscillator.

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line (X_{pk}) controls only a portion of the total capacitance of the circuit and therefore does not greatly affect the oscillator frequency. However, since X_{pk} in parallel with C_{pk} forms a voltage divider with C_{gk}, it has a considerable effect on feedback. X_{pk} may be inductive, purely resistive, or capacitive, depending on whether the cathode-line length is less than, equal to, or greater than a quarter wavelength at the frequency of oscillation. If X_{pk} is a high resistance, the feedback is determined entirely by the voltage divider composed of C_{gk} and C_{pk}. If X_{pk} is capacitive (greater than $\lambda/4$), then the two capacitances in parallel combine to increase C_k and results in an increase in feedback. Tuning the cathode line to slightly less than $\lambda/4$ makes it inductive and decreases C_k, which results in a reduction of feedback. Oscillations will cease if X_{pk} and C_{pk} in parallel can no longer be represented as a capacitor C_k. As can be seen by the third equivalent circuit, this oscillator is basically a Colpitts oscillator.

Advantages

The tuned-grid tuned-cathode type oscillator has three advantages: First, the cathode line offers a convenient means of connecting the load to the oscillator, because it is at ground potential with reference to d.c.; second, since only d-c voltages appear at the plate and only RF voltages appear in the cathode circuit, the two are not present in the same circuit and the high peak voltages present in a tuned-plate circuit are avoided; and third, the tuning of the oscillator is quite simple, the grid line being the frequency control and the cathode line the feedback control. There is some interaction between the tuning controls so that readjustment of each may improve both accuracy and output.

Tuned-Plate, Tuned-Grid, Tuned-Cathode Oscillators

A number of oscillators in the UHF range employ tuned lines in all three leads of the triode, as in the oscillator circuit illustrated in figure 8-11. So far as RF is concerned, all three tuned lines are grounded at their midpoints. The d-c circuits and filament circuits are identical to those described previously. In the circuit shown, the plate and grid lines, which are less than a quarter wavelength long, are labeled L_p and L_g respectively. The cathode line, which may be equal to, less than, or greater than a quarter wavelength, is labeled X_k.

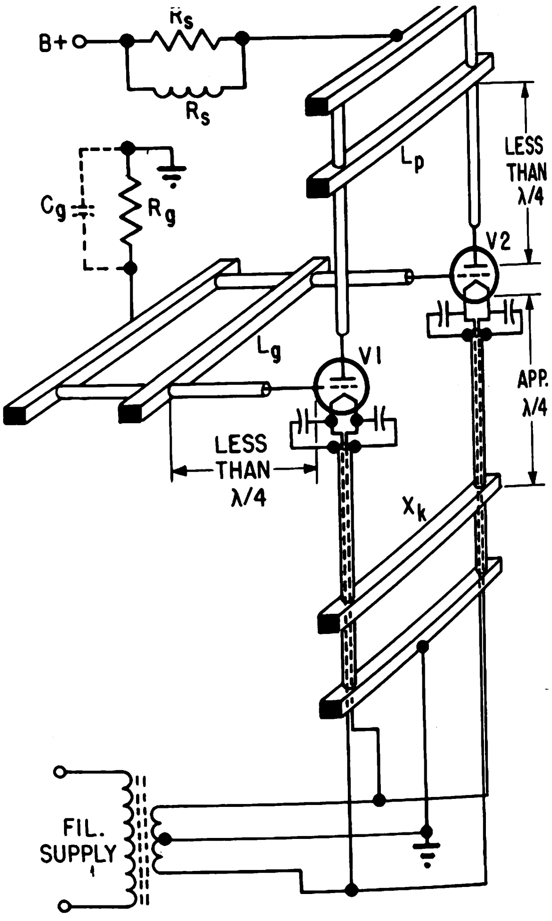

Figure 8-11.—Tuned-plate, tuned-grid, tuned-cathode oscillator circuit.

The equivalent circuit (fig. 8-12 (A)) shows both tubes, the inductances L_p and L_g center tapped to ground, and the unknown reactance X_k center tapped to ground. The interelectrode capacitances are not shown. Since the circuits of the two tubes are identical, the second equivalent circuit (B) shows only one tube. The inductances L_{pn} and L_{gn} and the reactance X_{kn} represent one-half of L_p, L_g, and X_k. The interelectrode capacitances are added. Examination of circuit (B) shows that if the cathode line is exactly a quarter wavelength so that X_{kn} becomes a high resistance, then the circuit is that of a conventional Colpitts oscillator. If the ratio of L_{gn} to L_{pn} is the same as the ratio of the reactances of C_{gk} and C_{pk}, there is no difference in potential between the cathode and ground and X_{kn} is in effect out of the circuit. This condition also

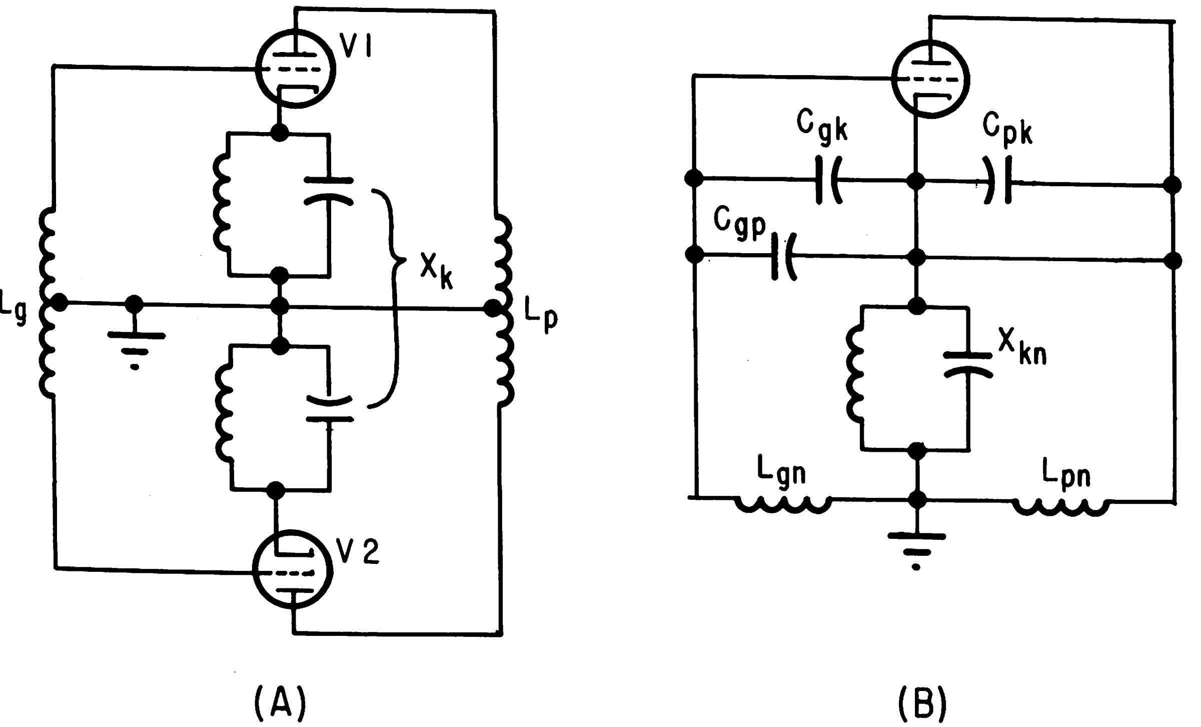

Figure 8-12.—Equivalent circuits of tuned-plate, tuned-grid, tuned-cathode oscillator.

ıces the circuit to that of a Colpitts oscilla- In either case, the frequency of oscillation etermined by the sum of the inductances of plate and grid lines, and the amount of feed- k by the ratio of C_{gk} and C_{pk}. Ordinarily ratio does not give the amount of feedback essary to cause oscillations; for best effici- , therefore, the cathode line is detuned from pure resistive quarter wavelength so that is capacitive or inductive.

laking X_{kn} capacitive or inductive while ing the sum of L_{gn} and L_{pn} constant does change the frequency of oscillation but does ease feedback. The exact amount of feedback nds on the ratio between L_{gn} and L_{pn}. , for example, consider the case where L_{pn} educed to zero and examine the nature of In this case X_{kn} is in parallel with C_{pk} as n in equivalent circuit of the tuned-grid l-cathode oscillator in figure 8-10 (B). , in controlling feedback, the effect of X_{kn} ges is the same as in the tuned-grid tuned- de oscillator—that is, the cathode line must creased in length to increase feedback or be eased in length to decrease feedback.

On the other hand, if L_{gn} is decreased to zero and L_{pn} is increased to equal the value of their former sum, then X_{kn} is in parallel with C_{gk}. Its effect on feedback then is just the opposite to that described. For example, if the cathode line is greater in length than a quarter wave, it becomes capacitive and the parallel combination C_{gk} and X_{kn} becomes a larger capacitance. This reduces the feedback. Reducing the length of the cathode line below a quarter wavelength makes it inductive, and the parallel combination becomes a smaller capacitance. This results in an increase in feedback. This demonstrates that FEEDBACK IS A FUNCTION OF BOTH THE RATIO OF L_{gn} AND L_{pn} AND OF THE TUNING OF THE CATHODE LINE. Since the frequency of oscillations is controlled by the sum of L_{pn} and L_{gn} and feedback is controlled by both the ratio of L_{pn} and L_{gn} and the cathode-line length, there are numerous settings of the three variable line lengths for any given frequency of oscillation and for proper feedback. This is readily understood if you consider that you have three variable elements with which to control two variables, and that there is a certain amount of interaction among the three controls.

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Pulsing of Triode Oscillators

There are two methods of pulsing UHF oscillators. One method employs separate modulator tubes; the other employs a self-pulsing oscillator.

THE SELF-PULSING OSCILLATOR

Most oscillators use grid leak bias or a combination of grid leak and fixed bias. An advantage of grid leak bias is that the amplitude of oscillation is limited and stabilized. Although you are probably already familiar with grid leak bias, it is discussed briefly again to introduce the subject of self-pulsing. In this connection notice the graphs of plate current and grid voltage versus time in figure 8-13. These waveshapes are the same for all oscillators which use grid leak bias. At zero time, plate voltage is applied but the grids are grounded so that a steady plate current flows. At time t_1 the ground is removed, and any random change in plate current will cause a change in voltage in the plate tank circuit, a portion of which is fed back to the grid circuit. Since this feedback is in the right phase and amplitude, the oscillations will grow in amplitude. Now each time the grid goes positive, grid current flows and charges the grid leak capacitor more negatively so that on each successive oscillation the average grid voltage (the bias) goes more negative. This continues until a state of balance is reached where just enough grid current is drawn to replace the charge which leaks off through the grid leak resistor during the remainder of the cycle. In addition, as the average grid voltage becomes more negative, the plate current flows for a shorter portion of each cycle until the flow is just sufficient to replace the energy lost in the tank circuit and to supply feedback to the grid circuit.

With perfect circuit elements and smooth electron emission, the circuit would oscillate indefinitely at this amplitude. But minute irregularities occur in the movement of electrons through resistors and conductors; also the emission from a cathode is always nonuniform. The nonuniformity is slight, but enough to affect the equilibrium in the oscillator circuit. Any slight decrease in current decreases the feedback; and if the time constant of the RC circuit is not extremely long, the bias is reduced slightly by discharge of the capacitor. The decrease in bias allows a little more plate current, which reestablishes the equilibrium at the previous level.

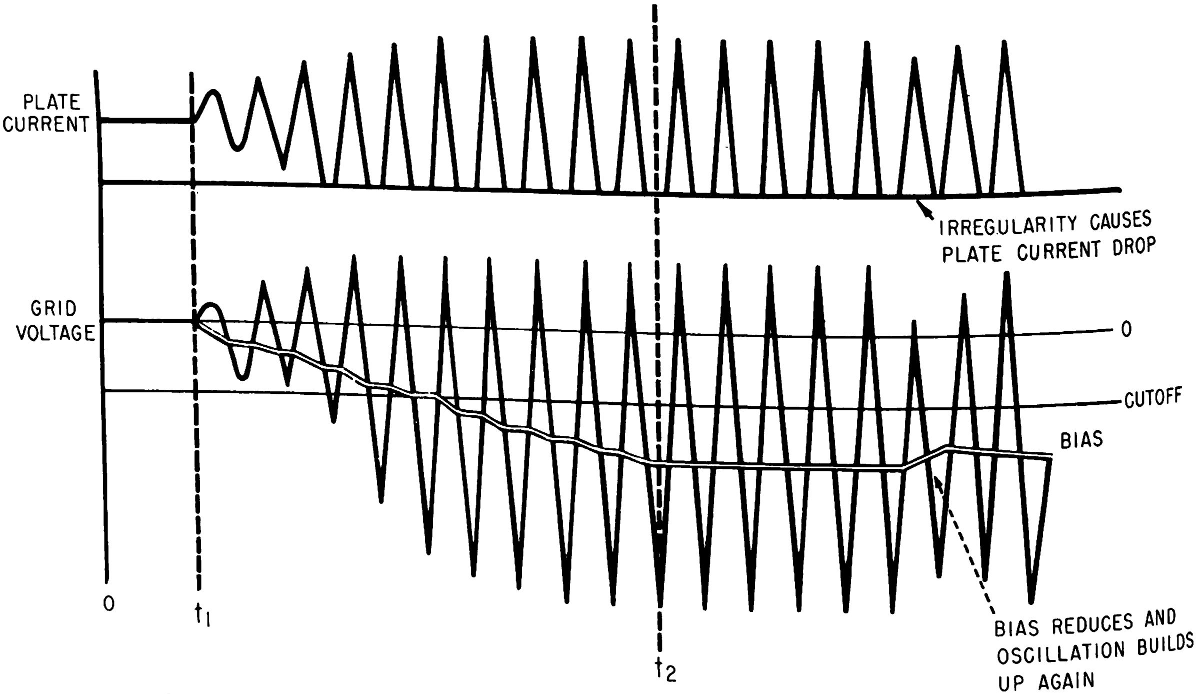

Figure 8-13.—Plate current and grid voltage vs time, showing buildup of oscillations.

a circuit with a long RC, however, the starts oscillating, then settles down to a ed condition as previously described, but light decrease in plate current now will compensated for by a lowered bias as in figure 8-14. The capacitor discharges owly. The resulting continued high bias its the feedback from being restored to the level, and after a few cycles the oscilla- ies out completely. The capacitor slowly rges and when its voltage drops below the voltage, the current again flows and the s repeats. For continuous operation, the the self-biasing circuit must be short to allow automatic adjustment of the bias anging conditions in the circuit. To make rcuit oscillate briefly, then stop, use a C. You can see that the time the tube re- cut off depends upon both the grid capac- nd grid resistance. By properly choosing values, you can have the oscillator operate r 2 microseconds and then cease operation) to 1,000 microseconds.

id voltage variations are shown in figure It is not possible to show the actual time ns since the OFF period is several hun- imes as long as the ON period.

In equipment which uses a self-pulsing oscillator it may be necessary to synchronize the oscillator with other circuits. One method of doing this is by applying a synchronizing sine wave to the grid. The results are shown in figure 8-15 (B) and (C). Without synchronization, the grid rises exponentially and crosses the cutoff line at a small angle which means that the actual time that oscillation begins may vary somewhat. Notice in (C) that the point at which the grid voltage crosses the cutoff bias line is much more definite.

The ideal condition would be for the grid voltage to cross the cutoff line at a 90° angle. For that reason a positive-going pulse is often applied when the grid voltage approaches cutoff. This assures oscillation at exact intervals of time. The oscillator is then synchronized to produce a desirable PRF.

Another means of obtaining a sharp crossover angle of the grid voltage is to return the grid to a positive voltage rather than to ground. Thus the grid voltage, in rising to a higher voltage than zero, will cross the cutoff line at a steep angle.

In order to make the DURATION of the pulse more definite, some self-pulsed oscillators use

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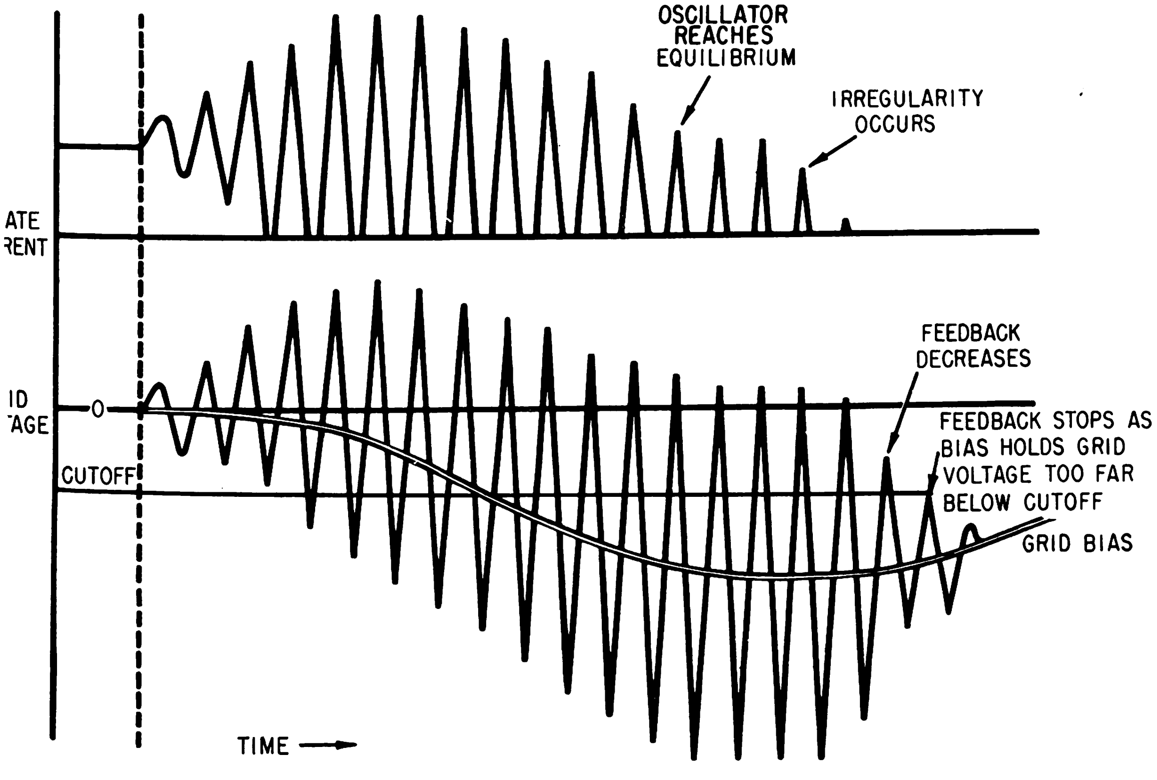
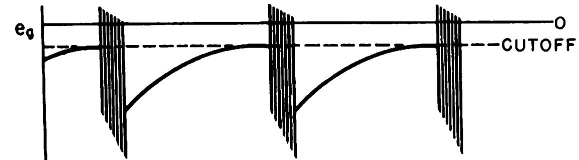
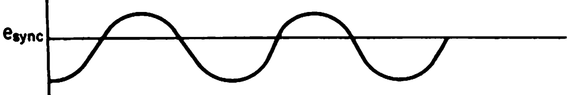

OSCILLATOR REACHES EQUILIBRIUM
IRREGULARITY OCCURS
ATE
RENT
FEEDBACK DECREASES
ID
AGE
0
CUTOFF
FEEDBACK STOPS AS BIAS HOLDS GRID VOLTAGE TOO FAR BELOW CUTOFF
GRID BIAS
TIME

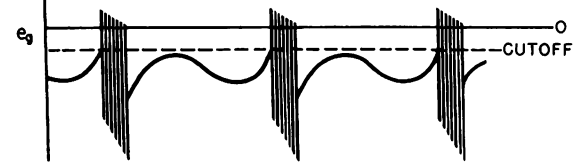
Figure 8-14—Effect of long RC.



(A) GRID VOLTAGE WITH NO SYNCHRONIZATION



(B) SYNCHRONIZING SINE WAVE



(C) GRID VOLTAGE WITH SYNCHRONIZATION APPLIED

Figure 8-15. —Grid waveshape with and without synchronization.

an artificial transmission line instead of the grid leak capacitor. This has the added advantage of making the operating conditions more nearly constant throughout the pulse. There are two places where the pulse line can be located. One is to put it in the grid circuit, as shown in figure 8-16, the other, in the cathode circuit. (The construction and operation of artificial transmission lines are explained in chapter 5.)

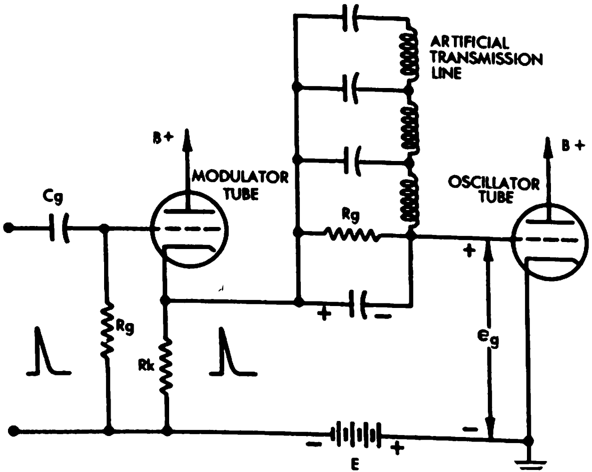


Figure 8-16—Oscillator circuit with pulse line in grid circuit.

A pulse line behaves like a long transmission line. Your chief interest is that it acts like a resistive circuit until the charging pulse has traveled the length of it and returned, at which time it is fully charged. This causes the voltage to change in two steps, the first step is from the bias E (figs. 8-16 and 8-17) to the voltage determined by the product of the grid current times the characteristic impedance of the line, and the second step is of a magnitude equal to the first.

The PRF is controlled by the synchronizing pulses, but the discharge of the pulse line through the grid resistor must be such that the grid voltage approaches the cutoff point by the time the next synchronizing pulse comes in. The discharge of the line is in steps, as shown in figure 8-17, which is the diagram of the grid waveshape of a line-controlled self-pulsed oscillator. The magnitude of the discharge voltage is determined by the relative values of resistance of Rg and the characteristic impedance of the line. Rg is usually much larger, hence the steps are small. These steps follow the general path of the exponential discharge curve with time constant R_gC_O, where C_O is the capacitance of the pulse line.

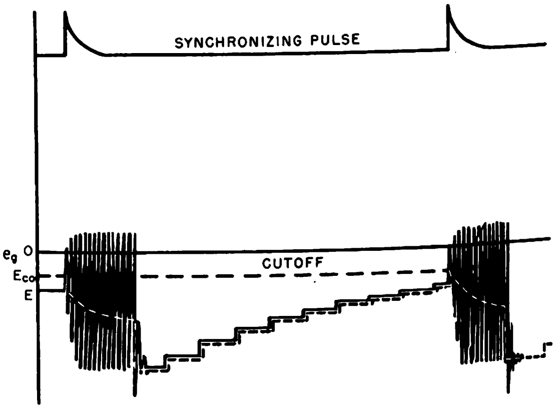


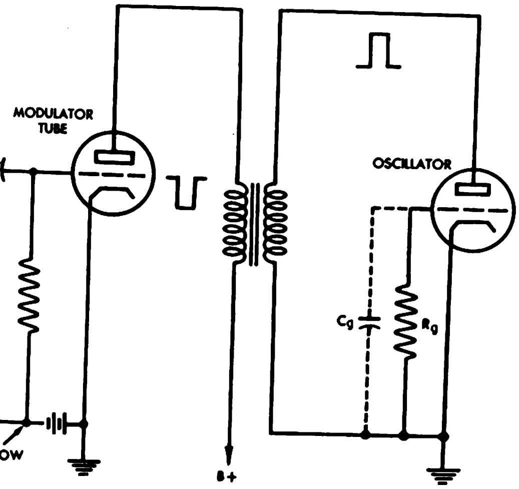
Figure 8-17. —Grid waveshape of a line-controlled self-pulsed oscillator.

SEPARATE MODULATORS

As previously mentioned, some triode UHF oscillators are not self-pulsed, but employ separate modulators. These modulators are very much like those used with magnetron oscillators, which are discussed later in this chapter.

merely note that the oscillator may be
modulated, grid modulated, or cathode
lated.

gure 8-18 shows a circuit for plate modu-
in which short positive rectangular pulses
pplied to the grid of the modulator tube
ing in a negative-going pulse at the plate.



re 8-18.—Plate-modulated oscillator.

ansformer is connected so that plate
is applied to the oscillator tube or tubes
rectangular pulses. RF components for
llator are not shown in the diagram. The
mer is specially constructed so that it
he rectangular pulse without undue dis-
Since the purpose of the transformer is
inversion, the question arises as to why
-going pulses are not applied to the
he modulator tube to cut it off and ob-
sitive-going pulse at the plate for use in
ng the oscillator. This would require
modulator tube, or tubes, conduct
uring all the cycle except during the
d would result in excessive waste of
he grid capacitance C_g of the oscillator
small, usually consisting of only the
ce to ground of the grid-tuned circuit.
o large, C_g might cause the oscillator
f-pulsed and cut itself off before the
pulse is over. Hence C_g and R_g have
t would cause continuous wave opera-
ate voltage were applied all the time.
llator pulse then is most effective in

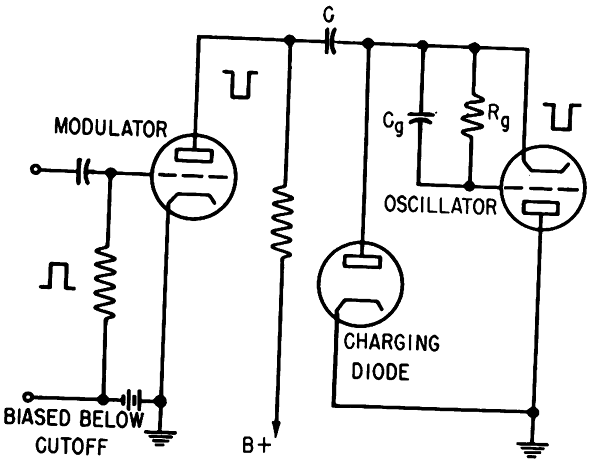


Figure 8-19. —Cathode-modulated oscillator.

controlling the output pulse. Oscillations must build up rapidly so that the leading edge of the output pulse will be as steep as possible. The plate voltage of the oscillator must remain constant throughout the pulse.

A cathode-pulsed (modulated) oscillator does away with the necessity of inverting the pulse, hence no transformer is used. (Refer to fig. 8-19.) The charging diode serves to recharge the coupling capacitor C between pulses. The capacitor must have quite a large capacitance so that it will not discharge appreciably during the pulse and thereby lower the plate-to-cathode voltage.

Grid modulation requires less power from the modulator for operation than either of the other two types of modulation. In grid modulation a positive-going rectangular pulse is applied to the grid and raises the grid voltage well above the cutoff point so that oscillation starts. Oscillation ends whenever the grid voltage drops to the normal bias. Usually the arrangement for this purpose is the one in which oscillation is started by a positive trigger pulse and ended by a self-pulsing grid bias voltage. C_g in the grid-pulsed oscillator shown in figure 8-20 is a small capacitance and is used to couple the pulse from the cathode of the modulator tube to the grid of the oscillator to insure a rapid rise of voltage at the grid and cause oscillations to build up quickly.

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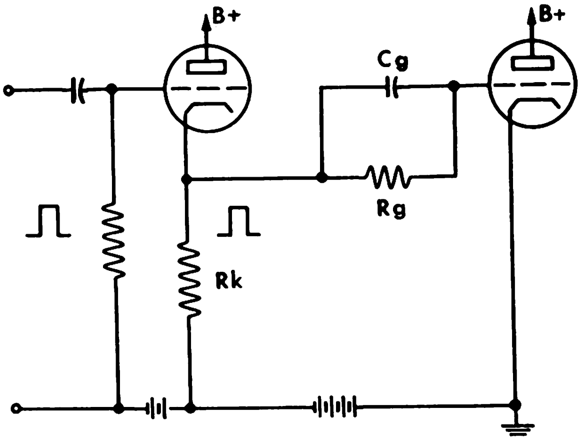

Figure 8-20. —Grid-modulated oscillator.

THE MAGNETRON OSCILLATOR AS A TRANSMITTER

A magnetron is used as the transmitting tube in almost all pulsed transmitters that operate at frequencies above 1,000 mc. The fact that transit time has little influence on the magnetron, whereas it is a limiting factor in the operation of conventional tubes, makes this type tube desirable for UHF pulsed operation. Some triodes may be used in transit-time oscillator circuits at radar frequencies, but their use is limited because of lower power output. There are some velocity modulated tubes, such as the klystron, which operate in the radar frequency range and are capable of greater power output than the triodes, but they too are not desirable since they are not particularly adaptive to high-power pulsed equipment used in present-day aircraft.

Magnetrons can produce pulsed power outputs at frequencies as high as or possibly higher than 25,000 mc. The power output of a magnetron may exceed 100 kilowatts at 10,000 mc. and 5 megawatts at 3,000 mc.

The magnetron, which is a self-excited oscillator, possesses rather poor frequency stability as compared with the more stable lower frequency oscillators (electron-coupled or crystal-controlled). However, by the use of AFC and proper design the magnetron provides adequate stability. The magnetron is a type of diode in which a magnetic field is set up perpendicular to the electric field existing between the cathode and the plate. The magnetic field is provided by an electromagnet in some instances but in most cases by a permanent magnet. Figure 8-21 shows a cutaway view of a magnetron tube. The tube consists of a cylindrical plate with a cathode placed coaxial with it. The tuned circuits in which oscillations take place are the resonant cavities in the plate.

The magnetron tube is a delicate instrument and must be treated as such if satisfactory operation is obtained. Handle the tube carefully, for should it be dropped or should the tube elements be moved there is the possibility of a plate-to-cathode short or at least a change in spacing of these elements. Either of these will cause the tube to operate improperly. The magnets, which are made of a special alloy called Alnico, are unusually strong. The field strength required is dependent upon anode potential and operating frequency. The magnets should not be struck with metallic substances or any hard material for this will cause them to lose magnetism.

A Multicavity Type Magnetron

Various types of magnetrons have been designed, but at the present time the most used type is the resonant-cavity (traveling-wave) magnetron. This is the only type that will be discussed in this chapter. A magnetron of this type is shown in figure 8-22. The plate structure is a solid block of copper in which the resonant cavities are cylindrical holes. (Figure 8-22 is an illustration of the magnetron shown in figure 8-21.) A narrow slot opens each cavity into the central portion of the tube and divides the inner plate structure into as many segments as there are cavities. Alternate segments are strapped together so that the cavities are placed in parallel so far as the output is concerned. This makes it possible to take the output from a pickup loop placed inside any one of the cavities. Since the outer conductor of the output coaxial line is at ground potential and connected to the shell of the magnetron, which is a part of the plate structure, there cannot be a high positive d-c voltage applied to the plate. The same result is realized whenever negative voltage is applied to the cathode, since it is equivalent to driving the plate positive.

Operation of the Magnetron Oscillator

The theory of operation of the magnetron is based on the motion of electrons in combined electric and magnetic fields.

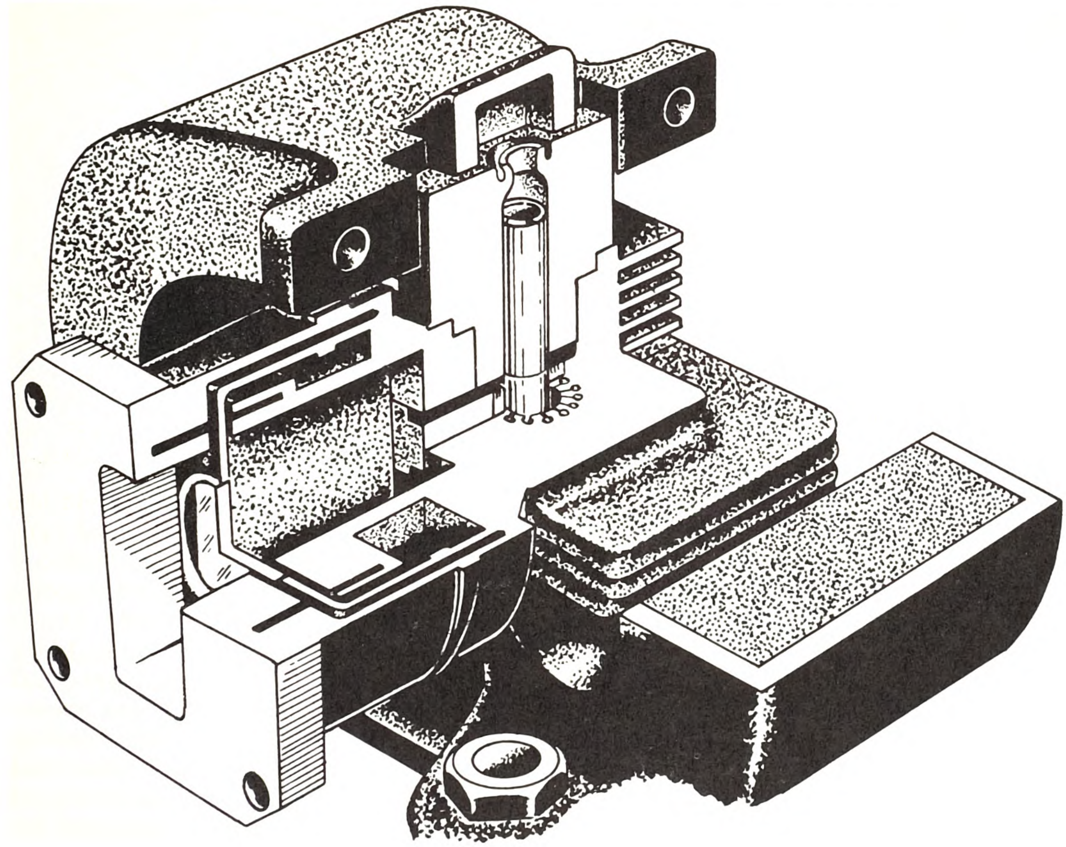

Figure 8-21. —Cutaway view of a magnetron.

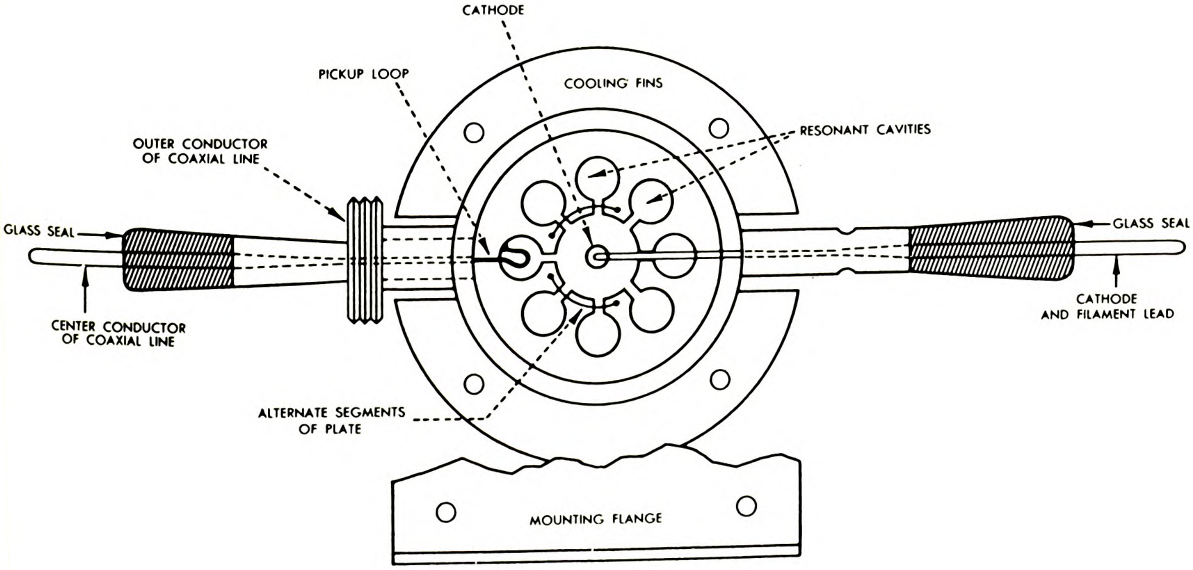
CATHODE
PICKUP LOOP
COOLING FINS
RESONANT CAVITIES
OUTER CONDUCTOR OF COAXIAL LINE
GLASS SEAL
GLASS SEAL
CENTER CONDUCTOR OF COAXIAL LINE
CATHODE AND FILAMENT LEAD
ALTERNATE SEGMENTS OF PLATE
MOUNTING FLANGE

Figure 8-22. —Multicavity magnetron.

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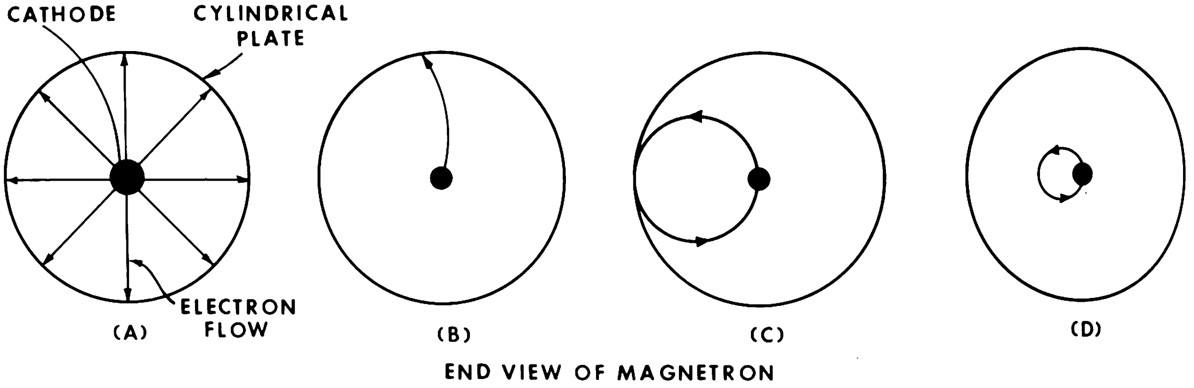

Figure 8-23. —Effect of magnetic field on electron.

EFFECT OF MAGNETIC FIELD ON ELECTRON FLOW

When no magnetic field exists, heating the cathode results in a uniform and direct electron movement from the cathode to the plate surrounding it (fig. 8-23 (A)). However, as the magnetic field surrounding the tube is continually increased, a single electron is affected as shown in figure 8-23 (B), (C), and (D). In (B) the magnetic field has increased to a point where the electron proceeds to the plate in a curved rather than direct path. In (C) the magnetic field has reached a value great enough to cause the electron to just miss the plate and return to the cathode in a circular orbit. This value is the critical value of the field strength. In (D) the value of the field strength has been increased to a point beyond the critical value and the electron is made to return to the cathode in a circular path of smaller diameter. Thus the size of the circle or the path that the electron follows around the cathode for a fixed cathode-to-anode potential will depend upon the strength of the magnetic field. Since these paths are determined by both magnetic and electric fields, they may be altered by changing the strength of either. The strength of these fields is critical for they determine the paths that the electrons follow and this, in turn, determines the stability of oscillation and tube efficiency. Under ideal conditions the electron paths are such that when curving past the slots of the resonant cavities, energy is released to the RF field.

PRINCIPLE OF OPERATION

The principle of operation of a magnetron is expressed in the process by which an electron acquires energy from the d-c field (existing between the anode and cathode) and releases it to the RF field to build up and sustain oscillations. (This happens when the d-c field accelerates the electron and causes it to acquire energy which is proportional to electron velocity.)

The cavity resonators are essentially a number of resonant circuits which are coupled together. The RF fields of these resonators may or may not be in phase. This phase relationship is determined by the amount of coupling between the cavities. Desired coupling may be acquired by connecting selected segments together. This is known as STRAPPING. By referring to figures 8-21 and 8-22 you can see an application of strapping.

Magnetrons may operate at different modes, which is to say that they may resonate at different frequencies. These frequencies are determined by the velocity at which the electrons whirl about the anode. A mode of operation that produces the greatest power output and efficiency is the π mode. The resonator is said to operate in the π mode when the phase difference of 180 degrees exists between successive cavities.

The electric component of the RF field at a given instant may be represented by dotted lines as shown in figure 8-24. In this figure, alternate segments are connected together or strapped to maintain a phase difference of 180 degrees between segments (π mode). The figure can be redrawn as a plane-electrode magnetron with field distribution as shown in figure 8-25. If motion of the electrons in figure 8-25 is considered, an electron at point B is accelerated to the right, one at point C is accelerated vertically, and one at point D is accelerated to the left. This action produces bunching so that

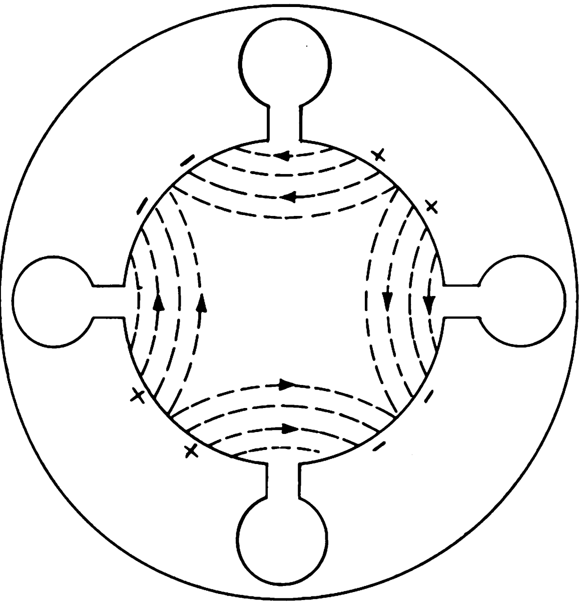

Figure 8-24. —Electric field distribution in a four-cavity magnetron.

unches of electrons pass the gaps the instant ie field causes maximum deceleration. The lectrons yield energy to the RF field, and inuce strong oscillations in the resonant cavity f which the gap is a part.

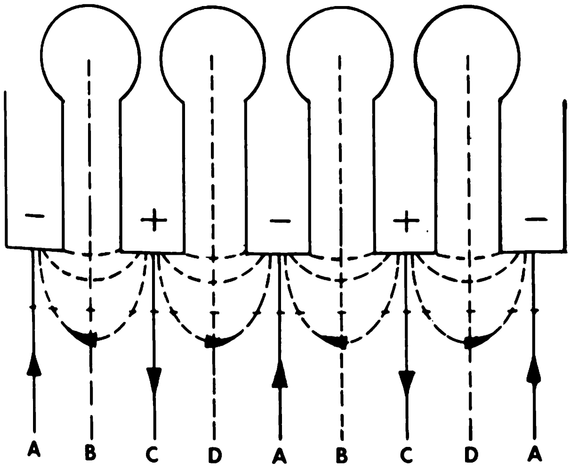

Figure 8-25. —Force lines in a plane-electrode magnetron.

Since the RF field changes in synchronism th the electron motion, the field lines of ure 8-25 may be considered as a traveling wave moving to the right in synchronism with the electrons. The bunching mechanism produces a spoke-shaped cloud of electrons that moves around the cathode in synchronism with the anode wave, as shown in figure 8-26.

As electrons are emitted from the cathode, they combine with the spoke-shaped field and simultaneously spiral towards the anode. Exceptions to this are the electrons that are emitted from the cathode at such time that they absorb energy from the RF fields. These will be quickly returned to the cathode. When electrons approach the opening of the resonant cavity they will give energy to the cavity providing the RF voltage across the opening is a decelerating field. (This is illustrated in figure 8-27.) Electrons on the RF negative side of the anode will be repelled by the approaching electrons. This provides the necessary "kick" to the oscillatory action of the cavity and thereby oscillation is sustained. As the electrons pass each cavity, they are slowed down when some of their energy is given up. After a few revolutions their velocity has decreased to the extent that they no longer continue in orbits but are attracted to the anode.

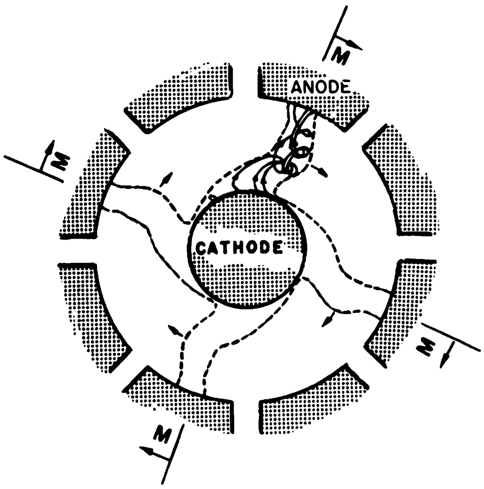

Figure 8-26. —Orbits of electrons of different phases in a cavity magnetron.

MODES OF OSCILLATION OF THE MAGNETRON

There are various modes of operation of a magnetron and they are identified by the number n, which specifies the number of cycles of variation of the field quantities that occur around the circumference of a circle surrounding the

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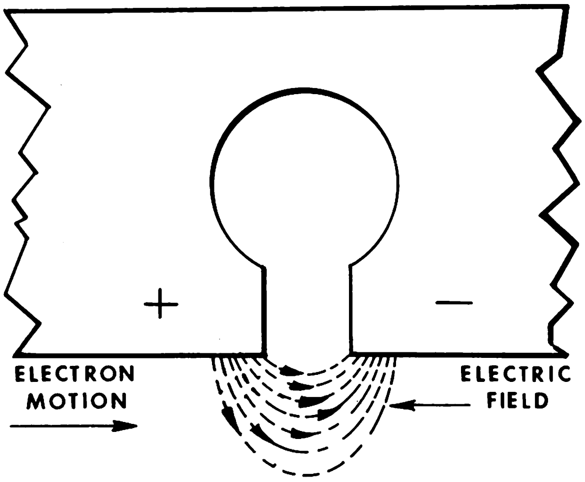

Figure 8-27.—An electron approaching the slot of a cavity at a time when it will give up energy in the cavity's RF field.

cathode. For each mode of oscillation of a magnetron, like those of other cavity resonators, there is a particular pattern of field variations. In the n equals zero mode, since the fields do not enter the anode cavities, the frequency of the mode is not controlled by the cavities; thus, this is an undesirable mode of operation. With the exception of the n equals zero and π modes, all modes are degenerative. The degenerative modes are in reality a combination of two modes that have the same resonant frequency. Due to unavoidable unsymmetrical construction of the anode segments the degenerative modes separate into two modes of slightly different frequencies.

Since a slight variation may cause a shift from one of these modes of operation to the other with a resultant change in output frequency, these modes are highly undesirable. Since the π mode of operation (previously described) is not degenerative, it is the desired mode of operation.

It is possible in an unstrapped magnetron to have an undesirable mode whose frequency may differ from the π mode frequency by less than 2 percent. The undesired mode will cause interference with the π mode of operation with such a small separation of frequency. With a strapped magnetron it is possible to obtain as much as 10 percent separation and thus eliminate the interference.

Additional Features of Magnetrons

The power output of a magnetron is obtained either by a coupling loop, as shown in figure 8-22, or by a transformer section of waveguide inserted into a cavity, as shown in figure 8-28. The filament leads are brought in through the glass enclosure as shown in figure 8-21.

Cathodes of magnetrons usually are oxide-coated, indirectly heated surfaces, as shown in figure 8-29. The pulse currents developed in magnetrons are larger than can be produced by thermionic emission alone. The large number of electrons are developed by secondary emission from the cathode as the cathode is back-bombarded by high-velocity electrons which are returned by the magnetic field. Metallic cathodes with good secondary-emmission characteristics have been used satisfactorily. The cathodes are designed with end shields to prevent the escape of electrons from the interaction space between the cathode and anode block. The design of anode blocks depends on the frequency and power output.

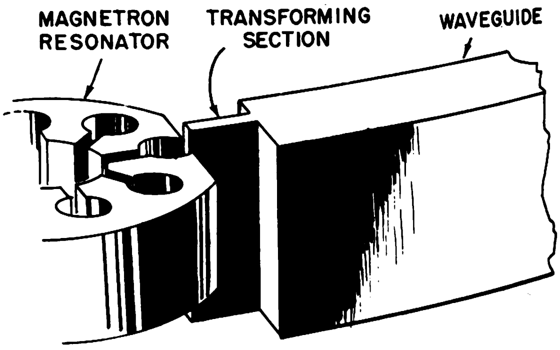

Figure 8-28.—Waveguide output section.

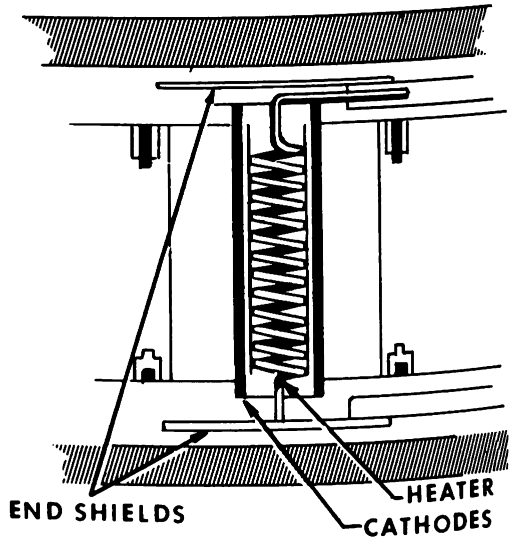

Figure 8-29.—Oxide cathode of a magnetron.

Another type of anode block, other than that shown in figure 8-21, is one that can be used unstrapped and is called the RISING SUN because of its physical shape. This magnetron, in π mode operation, requires no strapping because its irregular shape contributes to stability.

Magnetrons are difficult to tune. Since the resonant circuits are within the vacuum, they are inaccessible and mechanical tuning is slow. Electronic tuning can be used over a narrow frequency range and permits frequency modulation. Mechanical tuning is done by movement of a mechanical or magnetic device. Ranges of about plus or minus 10 percent of the mean frequency can be obtained by mechanical-tuning methods, two of which are shown in figure 8-30. In (A), movable tuning pins are inserted in each of the resonator cavities in order to vary the cavity inductance. These pins are made of a nonmagnetic material. When these tuning pins are inserted into the cavity they reduce the space available for the magnetic flux and thus the inductance is reduced and the frequency is increased. In (B), tuning is accomplished by varying the capacitance of the resonator. This s accomplished by moving a U-shaped ring in r out of grooves cut into the anode block. When he ring moves into the grooves, the frequency f the magnetron is decreased.

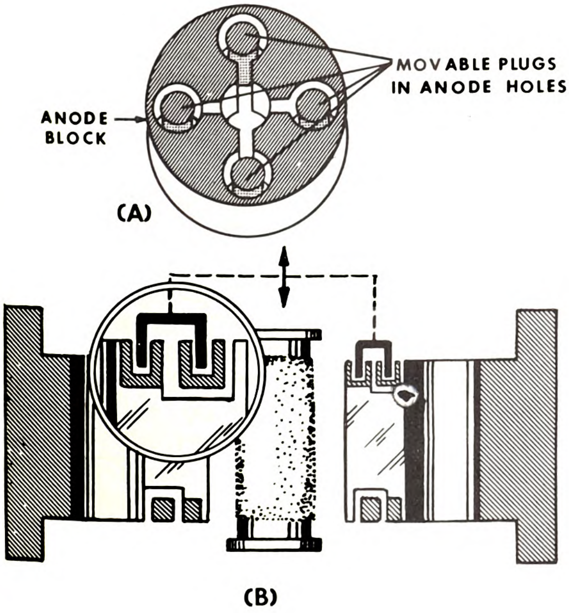

Figure 8-30.—Two types of tuning methods.

An application of magnetron frequency control as illustrated in (B) of figure 8-30 is used to frequency modulate the magnetron used in the aircraft altimeter, AN/APN-22. In this equipment the magnetron is modulated by a vibrating reed which varies the capacity across the strap on the anode cavity.

Since much of the heating of the cathode is obtained by the bombardment of the cathode by the electrons returning to it, the filament voltage is usually reduced when the high voltage is applied. This reduction is accomplished by adding a tapped filament transformer or a series limiting resistor in the circuit. In some equipments the filament voltage is removed completely.

Depending upon the type of magnetron and the type of equipment, it is sometimes necessary to season a new magnetron since it may not withstand the immediate application of full-power plate voltage. This is accomplished by subjecting the magnetron for a period of a few hours to filament voltage only. After this warmup period the plate voltage is applied (at low-power settings if possible) and a check is made to determine if the magnetron is arcing. Should arcing be detected, it may be necessary to remove the plate voltage and again subject the magnetron to an additional period of seasoning. The *Handbook of Service Instructions* will generally contain information in connection with this phase of maintenance.

In airborne equipments that use a magnetron the magnetic field is provided by a permanent magnet. Some magnetrons, called PACKAGED MAGNETRONS, have built-in magnets; thus, whenever a magnetron is replaced, the magnet must also be replaced. The packaged magnetron is finding wide use at the present time.

Theoretically, if the magnetic field of the magnetron is reversed, there should be no change in magnetron operation. This may not always be true since the construction of the magnetron may not be perfectly symmetrical. Thus, after removing a magnet, it is important that it be replaced in its original position. Generally the polarity of a magnet is indicated and this may be used as an aid in maintenance. The magnet should never be removed when the magnetron is operating since this will cause the electrons to strike the anode at high velocity and cause excessive heating. With no magnetic field there is nothing to limit magnetron current.

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Modulating the Magnetron

The modulator for the magnetron serves a double purpose—it determines the waveform of the output pulse, and it stores energy between pulses and releases it through the magnetron during the pulse.

The basic circuit for a magnetron modulator is shown in figure 8-31. In this circuit the storage element is charged through the charging impedance Z_{ch} and the load. It is discharged through the load when the switch is closed. On examining this circuit, you can see that closing the switch also completes a circuit containing the power source and Z_{ch}. This has little consequence, however, since the switch is closed for only a microsecond or so at a time and Z_{ch} is large enough to prevent any damage. It is well to become familiar with the components of some of the modulator circuit elements which are shown as blocks in this circuit. In the modulator, the source from which the storage element is charged may be either a d-c voltage or an a-c voltage. The magnetron requires a voltage of 10 to 15 kilovolts or higher for proper operation. In some types of equipment a transformer is used between the storage element and the magnetron to step up the voltage, while in many others a direct connection is made between the storage element and the magnetron. Actual charging circuits are discussed in a later section dealing with line-pulsing modulators. In these circuits the charging impedance may be a high resistance or a high inductance, or both. Its purpose is to control the charging time for the storage element and to prevent short circuiting of the source during the pulse.

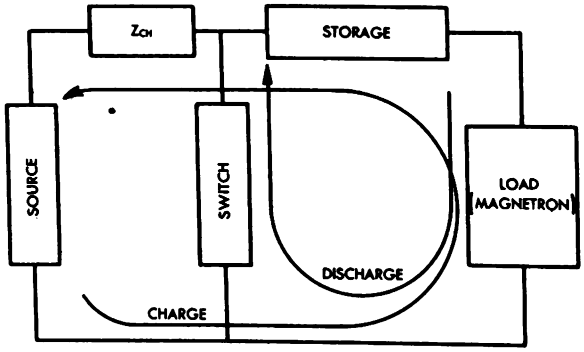

Figure 8-31.—Basic circuit for storage and release of energy in a modulator.

SWITCHING DEVICES

Switches for controlling the discharge time of pulse-forming networks may be of various types. Three types that will be discussed in this chapter are the ROTARY SPARK GAP, GAS DIODE, and THYRATRONS.

Rotary spark gaps are generally not used in aviation equipment because they are instable, must be enclosed in a pressurized chamber, and different repetition rates are difficult to obtain.

Gas diodes are used in some high-powered modulators. Figure 8-32 illustrates a gas diode type switch in which two cold cathode gas diodes are used. Some equipments use more than two of this type diode. These tubes are connected in series and an equal resistance is connected in parallel with each so that the high voltage will divide equally across each tube. This division prevents the voltage across either tube from becoming high enough to cause the tube to conduct.

As illustrated figure 8-32, the trigger pulse is applied across one diode and causes it to conduct. This conduction causes the triggered diode to appear as a closed switch which connects the full high voltage across the other diode and causes it to conduct. The conduction of this tube closes the network circuit. This circuit remains closed until the storage network discharges to the point where the diodes de-ionize. At this time the storage network begins to recharge.

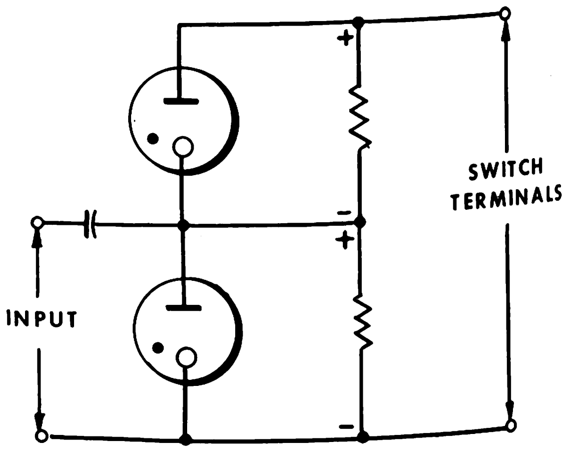

Figure 8-32.—Gas diode switch.

The thyratron is the more common switching device utilized in modulators. It is operated at cutoff until a positive trigger pulse is applied to

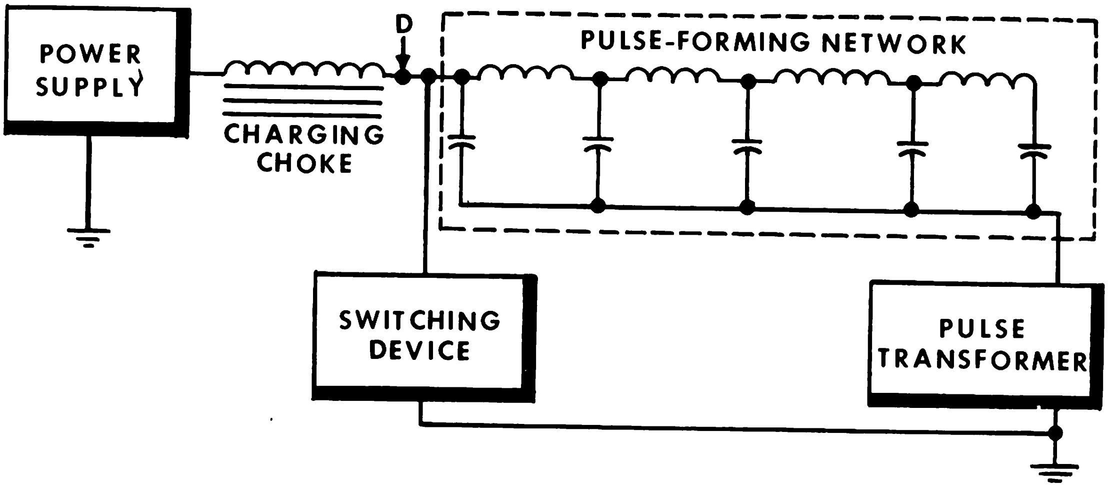

Figure 8-33. —Schematic diagram of a typical pulse-forming network and charging choke.

id. The tube then conducts until the net- circuit becomes discharged to the point e thyratron de-ionizes and the grid regains l. The most common thyratron of this s the HYDROGEN THYRATRON. While s diodes require an extremely high trigger e, the hydrogen thyratron requires a much voltage, approximately 30 to 100 volts. ormal life of this type of thyratron is ex- to be about 900 hours; tube life is in- d by repetition rate and not pulse widths, ng the widths do not exceed 5 micro- s. The two advantages of the thyratron ng system are the accuracy of the firing d the fact that the thyratron is not affected impedance of the trigger source.

-FORMING NETWORKS

pulse-forming network consists of a of coils and capacitors in an arrangement t shown in figure 8-33. There are other ements for the elements in the PFN, but rangement shown is the most common. lse-forming networks have a CHARGING in series with the input. The choke is resonant with the line and isolates the supply from the switching device during ge time. The LC constants in the net- e carefully selected to provide a pulse roper shape and duration. The coils and rs must be rated to withstand the high s and currents they encounter in building igh-powered pulse.

The PFN and charging choke are designed so that their combined impedance matches the output load as nearly as possible when the network is switched. The output line therefore appears as an infinitely long transmission line when the switch is closed. This reduces reflections in the charging circuit during the discharge interval. During the charging time, however, when the switch is open, the network is resonant. It can be shown that when a voltage is suddenly applied to an inductance and capacitance in series, the voltage at the resonant frequency of the circuit oscillates in such a mannner as to give a sine wave, the amplitude of which is almost twice the applied voltage.

For maximum voltage production the pulse recurrence frequency should be equal to twice the resonant frequency of the charging circuit. To permit operation at more than one repetition rate, a charging diode must be connected in series with the charging choke. This diode would be connected at point D in figure 8-33. Figure 8-36 shows a multi-PRF modulator using a charging diode. The pulse-forming network is thus prevented from discharging after the maximum oscillation is reached. The diode also causes some additional damping in the circuit, so that the maximum value is slightly less than the original maximum value of almost twice the value of the d-c supply.

Because the diode maintains the voltage at practically twice the d-c supply for a considerable time the interval between times of closing

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the switching device can have any value greater than a half cycle of the charging oscillation.

The output voltage pulse from a d-c resonant charging network is about half the voltage to which the network is charged because the line impedance and load impedance are equal. Since the network is charged to nearly twice the supply voltage and the output pulse voltage is half the network charge, the usable voltage in the output pulse is about 0.9 of the supply voltage.

This type of pulse network is usually sealed in a metal box filled with oil which acts as an insulator. For that reason it is sometimes called a POTTED NETWORK. It is impossible to replace components in the line. Some lines using only a few elements are not potted. These do not generally give as nearly a rectangular output pulse, due to the smaller number of sections.

THE PULSE TRANSFORMER

In the circuits discussed thus far the load can be a magnetron and its associated circuits or the primary of a pulse transformer which has its secondary connected to the magnetron. The use of a high-voltage step-up transformer to furnish voltage for the magnetron makes possible the use of lower voltages in the pulse-forming network and thus simplifies the insulating problem. An advantage in using a transformer with two secondaries (bifilar windings), as shown in figure 8-34, is that it avoids having high voltage in the magnetron filament transformer. The bifilar windings have the same voltage induced into each since they are wound side by side. This winding makes it possible to connect a filament transformer, without high-voltage insulation, to the heater of the magnetron and to couple the high-voltage pulse between the cathode and plate.

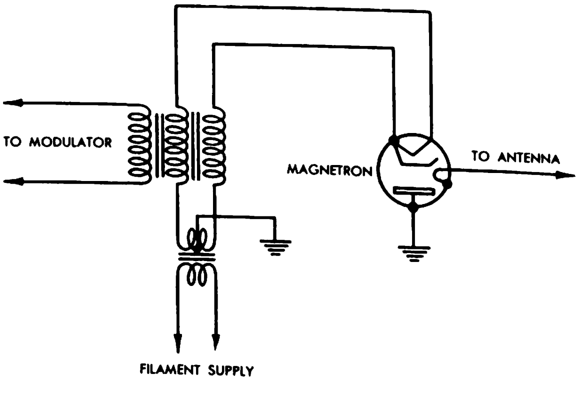

Figure 8-34.—A transformer with two secondaries makes possible the grounding of the filament transformer secondary.

A third need for the high-voltage pulse transformer is matching impedances, particularly where the radar antenna is remote from the set itself. Since the use of long transmission lines between the magnetron and the antenna make the magnetron's operation somewhat erratic, it is desirable to have the magnetron near the antenna. This necessitates the use of long lines to carry the modulator pulse to the magnetron. In order to be able to use 50-ohm line for this purpose and still obtain an impedance match with the impedance of the magnetron (approximately 1,000 ohms), it is necessary to use a 4 1/2 to 1 step-up transformer at the magnetron end.

The pulse transformer must be specially designed because there are very high frequency components present in a rectangular pulse of such short duration. The core is usually silicon steel and has laminations in the order of 0.003 inch in thickness. In general a good pulse transformer must have low leakage inductance, low interwinding capacitance, and high primary inductance.

Types of Modulators

There are two types of modulators—the line-pulsing modulator and the driver-hard-tube modulator. The line-pulsing modulator stores energy and forms pulses in the same circuit element. This element is usually the pulse forming network. The driver-hard-tube modulator forms the pulse in the driver; the pulse is then amplified and applied to the modulator. The hard-tube modulator has been replaced by the line-pulsed modulator. The reasons for this replacement are that the hard-tube modulator has lower efficiency, its circuits are more complex, a higher power supply voltage is required, and it is more sensitive to voltage changes.

The line-pulsed modulator is easier to maintain because of its less complex circuitry and, for a given amount of power output, it is more compact and light. Since it is the principally used modulator in aviation radar, it is the only type that will be discussed at great length.

Before discussing the line-pulsing modulator, it is well to consider briefly the various types of charging circuits and to note their advantages and limitations. To do this, study figure 8-35 which shows the various types of charging circuits.

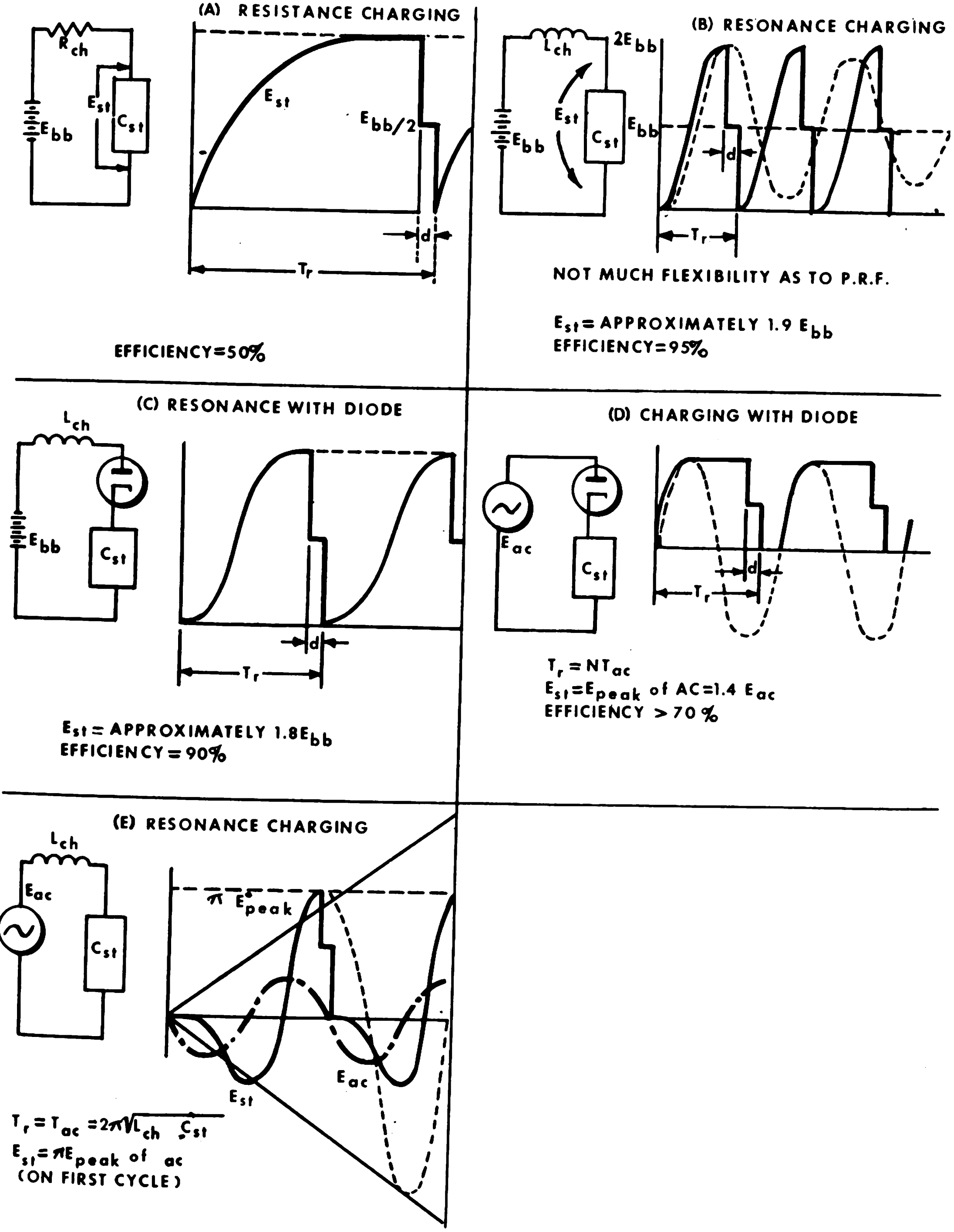

Figure 8-35. —Types of charging circuits.

d-c resistance charging circuit (A), line or storage capacitance is repre- C_{st}. It is charged through R_{ch} to the value of the d-c voltage. During the pulse one-half the d-c voltage is applied to the magnetron (assuming the line impedance is matched to that

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of the magnetron) for a period of time determined by the line components. This is only 50 percent efficient. Therefore, it is necessary that the d-c voltage be twice the value needed for the magnetron. The time constant $R_{ch}C_{st}$ must be large in comparison to the period of the repetition frequency. This insures that the line will fully charge between pulses but will not discharge appreciably through the source and R_{ch} during the pulse.

In the d-c resonance charging circuit (B), resistor R_{ch} is replaced by an inductance L_{ch}. As C_{st} charges, the current through L_{ch} builds up a magnetic field. This field causes current to continue after C_{st} is charged to E_{bb}. The charge will reach a peak of approximately 1.9 times E_{bb} after which it starts decreasing. If the modulator is triggered at the instant of maximum charge, the voltage applied to the magnetron is about 95 percent of E_{bb}. This necessitates that the resonant frequency of L_{ch} and C_{st} be one-half the PRF of the radar. The firing time is very critical if advantage of the maximum voltage is to be obtained.

The difficulty encountered in the preceding circuit is overcome by adding a diode in series with the charging element. Circuit (C) prevents the line from discharging after reaching its peak. This means that the time of firing can occur any time after the peak is reached. Therefore, the frequency at which L_{ch} and C_{st} resonate is equal to or greater than one-half the PRF. The disadvantage of making the firing time less critical is that the voltage to which the pulse forming line charges is decreased by the drop across the diode to about 1.8 times E_{bb}. This makes the efficiency of this circuit about 90 percent.

Circuit (D) has the pulse line charging from an a-c source. In this circuit, the charging line is prevented from discharging by a diode in series with it. Further, in this circuit it is necessary that every trigger pulse come at a time when the diode plate is negative; otherwise the diode and the switch will short circuit the a-c source. Therefore,

$$T_r = NT_{ac}$$

where

T_r = time between trigger pulses

N = 1 or some other whole number

T_{ac} = time of a cycle of the a-c source voltage

The voltage to which the line charges is almost the peak value of the a-c wave so that the efficiency is about 70 percent.

In circuit (E), the diode is replaced by the inductance L_{ch}. This inductance, along with C_{st}, forms a resonant circuit which is resonant at the frequency of the a-c supply voltage. In this circuit the switch may be closed at any peak of oscillations. Usually it is closed at the first peak. At this time the voltage is approximately π times the peak value of the a-c voltage. In addition $T_r = T_{ac} = 2\pi \times \sqrt{L_{ch}C_{st}}$. If the switch is closed at the second peak, the voltage will be nearly twice as high. This type of charging gives voltages higher than the source voltage.

THE LINE-PULSING MODULATOR

This discussion will serve a dual purpose—it will explain the theory of operation of a typical line-pulsing modulator and will also summarize the function of the various modulator components already explained in this chapter.

The modulator (fig. 8-36) is of the line-pulsing type. The pulse-forming network undergoes a charge-discharge cycle at a rate (PRF) which is established by the master-trigger generator and which is consistent with the pulse width in use and the maximum power capabilities of the transmitter. The modulator consists of artificial-line pulse-forming network Z401; hydrogen-thyratron switch tube V405; holdoff or charging diode V403; inverse-diode V404; resonant charging choke L401; and magnetron pulse transformer T404, the double-wound secondary of which supplies a pulse of power to the magnetron cathode circuit each time the line is discharged. The switching device which controls the discharge of the line is a hydrogen-thyratron tube controlled by the trigger from the radar's synchronizer.

When system power is applied, current to charge the pulse-forming network is drawn from the power supply through resonant charging choke L401 and charging diode V403. The flow of this current establishes a magnetic field in the resonant charging choke. Charging is rapid up to the point at which the pulse-forming network charge nearly equals the peak power supply voltage, approximately plus 2,500 volts d. c. The rate of charge drops sharply, and the magnetic field built up in the resonant charging

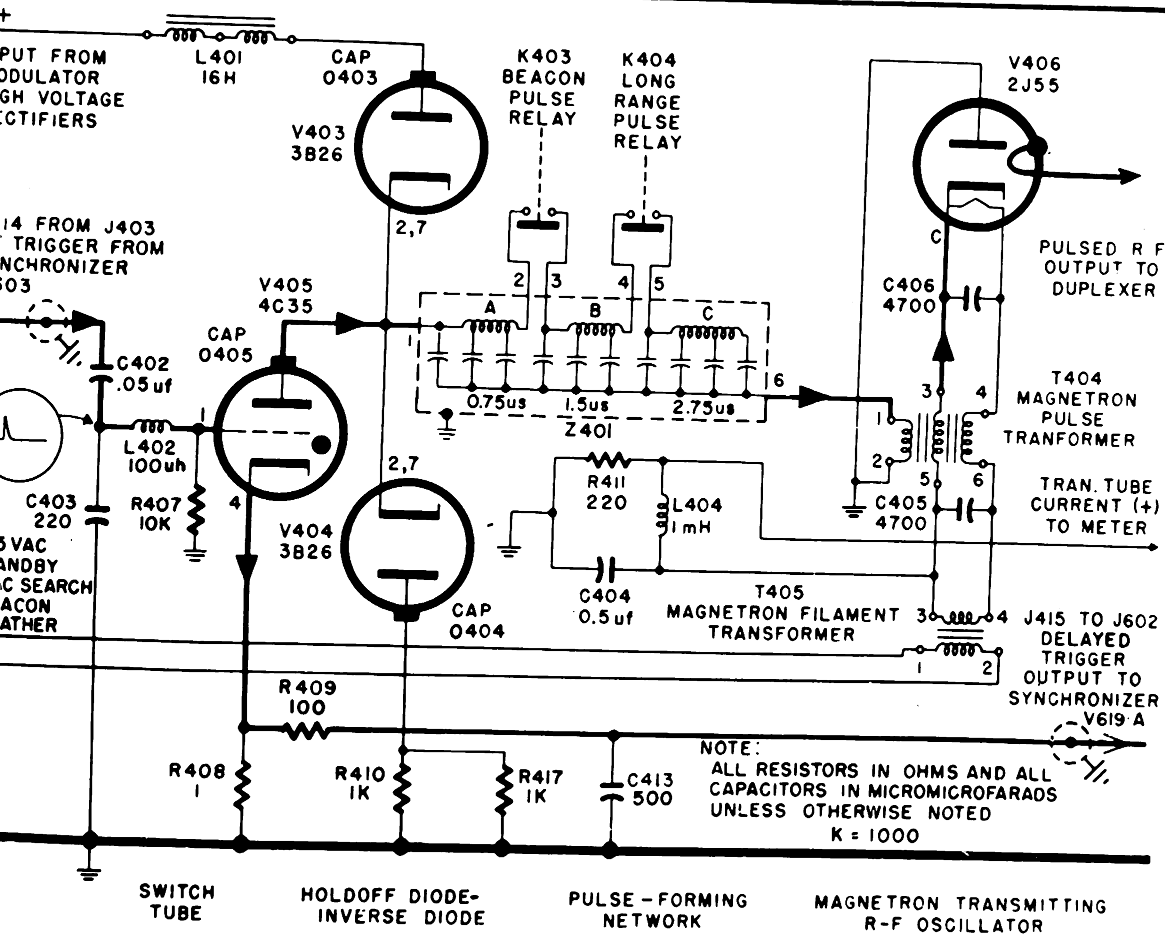

Figure 8-36. —A typical line-pulsing modulator and magnetron circuit.

collapses. By this self-inductance, a volt-
proximately twice the power supply peak
e is rapidly established. The tendency of
onant charging choke to oscillate is halted
ly at its first positive peak by the rectify-
ion of the charging diode and the pulse-
g network is held at this high potential.
rge of the capacitors within the pulse-
g network is prevented by charging diode
Inverse-diode V404, and thyratron switch
re inoperative and hence appear as infinite
nces and do not provide a discharge path
network.

master-trigger generator in the syn-
er supplies a trigger voltage to the grid
thyratron switch tube through the d-c
g capacitor C402. When triggered the
ube ionizes and provides a closed circuit
discharge of the pulse-forming network.
scharge continues for a definite period of
a constant rate, determined by the constants of the pulse-forming network. A negative square-shaped pulse is impressed across the primary winding of the magnetron pulse transformer T404. The width of the transmitter pulse varies in a manner determined by the number of sections of the pulse line in use, as determined by the beacon pulse relay K403 and long-range pulse relay K404. Since the primary of transformer T404 is matched with the 50-ohm surge or characteristic impedance of the pulse-forming network or line, there is an equal division of voltage between these two units. Approximately 2,500 volts is impressed on the primary of T404. The turns ratio of T404 causes a voltage step-up of 1 to 5. Thus a negative pulse of approximately 12 kilovolts is placed on the cathode of the magnetron V406. The peak power of this pulse is in the order of 150 kilowatts. Output of the magnetron approximates 50 kilowatts due to losses in this tube and the associated circuits.

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Gas bursts (arcing) occur occasionally within the magnetron. This condition causes momentary pulse-transformer impedance mismatching, and a small voltage of polarity opposite to that of the modulator pulse may appear across the pulse-forming network after the pulse. This small reverse voltage is in series with the power supply voltage at the start of the next charging cycle. Hence the total voltage available to produce the charging oscillation is increased, and the pulse-line voltage may build up to a value great enough to break down the thyratron. This condition is overcome by connecting inverse diode V404 in parallel with the thyratron. The diode bypasses the reversed charge of the pulse-forming network.

The pulse-forming network is composed of aircore inductors and mica capacitors. It is divided into three sections of artificial transmission line, all within the same container. Each part is a complete network. The connection of the three parts by relays K403 and K404 increases the width of the pulse. When only the first section Z401-A is in use, 0.75-microsecond pulses are generated. Addition of the second section increases the pulse period by 1.5 microseconds for a total of 2.25 microseconds. With all three sections connected, pulses of 5.0-microseconds duration are generated.

During beacon operation only relay K403 is energized, thus the A and B sections of Z401 are connected in the circuit to form a 2.25-microsecond pulse. During long-range search operation both relays, K403 and K404, are energized; thus all three sections of Z401 are connected in the circuit to provide a 5.0-microsecond pulse.

Resonant charging choke L401 not only doubles the pulse-system voltage before firing, but it effectively isolates the power supply from the rest of the modulator during the relatively short periods of pulse duration. It also prevents the power supply from shorting through the switch tube during de-ionization.

Resistor R407 functions as a grid leak for the thyratron switch tube. Capacitor C403 and choke L402 form a filter network to prevent the reflection of the switch tube transients into the synchronizer. Switch tube current, flowing through the cathode resistor R408, generates a trigger pulse which is used for synchronizing the range mark start-stop multivibrator located in the synchronizer. Resistor R409 and capacitor C413 improve the trigger shape by removing ripple at the top of the pulse.

The cathode of the magnetron is internally connected to one side of the filament line. Input to the magnetron is applied by the modulator through the magnetron pulse transformer T404. The design of the pulse transformer provides two secondaries of similar electrical characteristics, one in each leg of the magnetron filament supply. This bifilar secondary winding maintains an equal and in-phase pulse voltage on both sides of the filament and effectively isolates the high-voltage modulator pulse from the low-voltage magnetron filament transformer T405. Capacitors C406 and C405 compensate for slight electrical differences between the pulse transformer output windings to prevent the appearance of high pulse voltages across the filament.

The d-c plate current of the magnetron flows through the cathode circuit of V406, pins 3 and 5 of the pulse transformer, L404 and the 220-ohm resistor R411. Coil L404 (1 millihenry) blocks peak pulses but passes average current through the magnetron current meter. Capacitor C404 offers a low impedance to magnetron pulses and integrates them for metering. Negligible current is generated within the magnetron during quiescence, but the average or d-c current summed over a period of pulsed operation is of high magnitude. Longer pulse periods at lower PRF tend to balance shorter pulse periods at higher PRF, resulting in a nearly uniform duty cycle regardless of the radar function being performed. Note that while 115 volts is applied to the magnetron filament transformer during standby it is reduced to 65 volts when the high voltage is applied to the modulator.

VELOCITY-MODULATED TUBES AS LOCAL OSCILLATORS

In radar, most receivers use 30 or 60 mc. IF frequencies. In receiver operation, a highly important factor is the stability of the frequency of the local oscillator which generates the frequency that differs from the transmitted frequency by the IF. For example, in a radar receiver which receives a frequency of 3,000 mc., a frequency shift in the local oscillator as much as 0.1 percent would be a 3-mc. frequency shift. This is equal to the bandwidth in most receivers and would cause a considerable loss of amplification in the receiver.

Still another consideration in radar is a receiver which uses a crystal diode mixer. In this er the power required of the local oscil- s small, being only 20 to 50 milliwatts 3,000-mc. region. Due to the very loose ıg, only about one milliwatt actually s the crystal.

hird requirement of a local oscillator is must be tunable over a range of several ycles. This is to compensate for changes transmitted frequencies and in its own ıcy.

order to obtain a receiver IF signal of ing frequency it becomes necessary to ıe frequency of the local oscillator. The oscillator must be caused to change its ıcy by the same amount that the received changes, thereby maintaining a constant quency. The frequency changing of the oscillator should occur automatically as ceived signal frequency changes occur. cases where the RF units are located in ote position, it is desirable to mount the ter section of the receiver remotely also. nsures that the IF frequency rather than ınsmitted frequency is cabled back to the er, but makes it necessary that the local tor be tuned from a position some dis- away, preferably by varying the voltage l to it.

ause the reflex-velocity-modulated tube stron meets all requirements of a local tor better than any other type of tube now luction, it is used almost exclusively in vave radar receivers. The klystron is equently used in microwave signal gen- or other applications where a source of vave RF energy of low power is required. lowing deals with its operation. In it the resonators are treated as parallel reso- rcuits, as was explained in the theory of onant cavity in chapter 7.

THEORY OF OPERATION

inally klystrons contained two cavity ors. When a signal was applied to the sonator, the second resonator would also the same signal in an amplified form. y providing the tube with the proper ex- coupling a part of the output resonator's ould be returned to the input. This feed- ısed the tube to function as an oscillator. NG (to be explained later) was produced irst resonator and the output was taken second resonator. In the following discussion of the reflex klystron notice that the bunching is produced by the same cavity from which the output is taken.

In the circuit of the reflex klystron (fig. 8-37), note the arrangement of the electrodes and the voltages involved for operation. Electrons are emitted by an indirectly heated cathode. These electrons are attracted by the cavity grids (buncher grids) which are more positive than the cathode by the voltage E_a. The control grid is located between the cathode and the cavity grids and is for the purpose of controlling electron flow. It also has a positive potential which is usually about two or three hundred volts. The electrons emitted from the cathode travel toward the cavity grids at a velocity determined mainly by E_a. Most of the electrons pass through the control grid, the cavity grids, and continue on toward the repeller plate. After passing the cavity grids they approach a region where the electrical field opposes their motion since the repeller plate is negative with respect to the cathode by the voltage E_r. This voltage is variable and equals about minus 100 volts. This, in turn, makes the voltage from repeller to cavity grids three or four hundred volts and slows down the electrons causing them to come to a stop, after which they reverse direction and pass back through the grids.

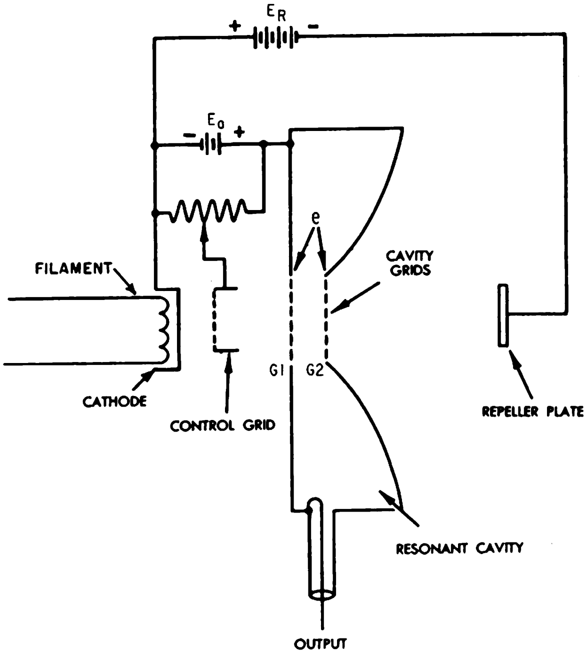

Figure 8-37. —Circuit of a reflex klystron oscillator.

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Most of these returning electrons are collected by the cavity grid nearest the cathode, the accelerating grid, or the shell. Those that are not collected continue on toward the cathode until they are reversed in direction by the accelerating field and sent back through the cavity a third time. These electrons that are not collected cause improper tube operation; this undesirable feature is partially overcome through tube design.

It is important to consider the cause of oscillations in resonant cavities. In most oscillators, oscillations start from some irregularity in current flow, such as a transient that results from voltage being suddenly applied to the tube or from shot effect. With this in mind, assume that the oscillations in the resonant cavities are already taking place. From this assumption examine the source of the energy needed to sustain these oscillations.

With the tank circuit oscillating, a high-frequency voltage, e, appears between the two cavity grids. This causes the electric field between these grids to reverse twice during each complete cycle of operation. In this condition, as the electrons approach these grids, the electron stream is uniform. The time that is required for the electrons to pass through the small distance between the grids is small compared to the period of oscillations. Electrons which enter the space between the grids when e is zero will encounter no a-c electrical field and they will pass on through at the same velocity. The electrons which enter the space when e makes grid G_2 positive with respect to grid G_1 will encounter a field which tends to accelerate them. The amount of acceleration is a function of e. Electrons entering the space when e is reversed in polarity are decelerated. The change in velocity due to acceleration and deceleration is small in comparision with the original velocity. Those electrons which are accelerated most will travel farther toward the repeller plate before being turned back, while those that are decelerated most will be turned back sooner. Thus it is conceivable that with the proper magnitudes of e, E_a and E_r, electrons returning to the cavity grids will arrive in bunches.

Figure 8-38 shows the position of electrons in the tube at various times during their transit. The zero distance position, taken as the baseline in the graph, is midway between the cavity grids. Electron A, which arrives when G_2 is positive, is accelerated and travels farther before being turned back; electron B is unaffected; electron C is decelerated and turns back after a shorter excursion. Hence, in the diagram these electrons and the ones passing through at intermediate times are shown as arriving back at the grids at the same instant of time. This is the ideal situation, but it is not difficult to see that electrons will return to these grids in a stream which varies in intensity at the frequency of the oscillations. Due to this fact this tube is called a REFLEX-VELOCITY-MODULATED tube because the electrons reverse direction and travel through the interelectrode space twice.

On the return trip the electric fields set up by the voltage e again act upon the electrons. Since they are now traveling in the opposite direction, they will be decelerated if they return when G_2 is positive and accelerated if they arrive when G_2 is negative. When an electron is accelerated by an electric field, its kinetic energy increases; this additional energy is taken from the electric field. On the other hand, an electron which is decelerated gives up energy to the electric field. If the bunches of electrons can be made to arrive back when G_2 is positive, they will give up energy to the alternating field. For maximum transfer of energy the bunches must arrive when G_2 is maximum positive. The question arises as to where this energy originates. Remember that if the electron stream from the cathode is uniform, some electrons are accelerated and some are decelerated on the outbound trip by the electric field of e. On the average, as many electrons absorb energy from the field as give up energy to it. Hence, very little net energy is taken from the oscillating circuit during the bunching process. The average kinetic energy of the electron is that imparted to it by the d-c voltage E_a. Thus, some of the energy taken from the d-c electric field is transferred to the a-c field to sustain the oscillations. The power output is taken from the klystron with an inductance loop located inside the resonant cavity.

Modes of Operation

It is not necessary that the bunches of electrons return to the grids on the first positive swing of G_2. Figure 8-38 indicates that if the bunches arrive on the second positive swing, the net result is still the same. You can see that the time in transit for the average electron B is 3/4 cycle, 1 3/4 cycles, 2 3/4 cycles, and so

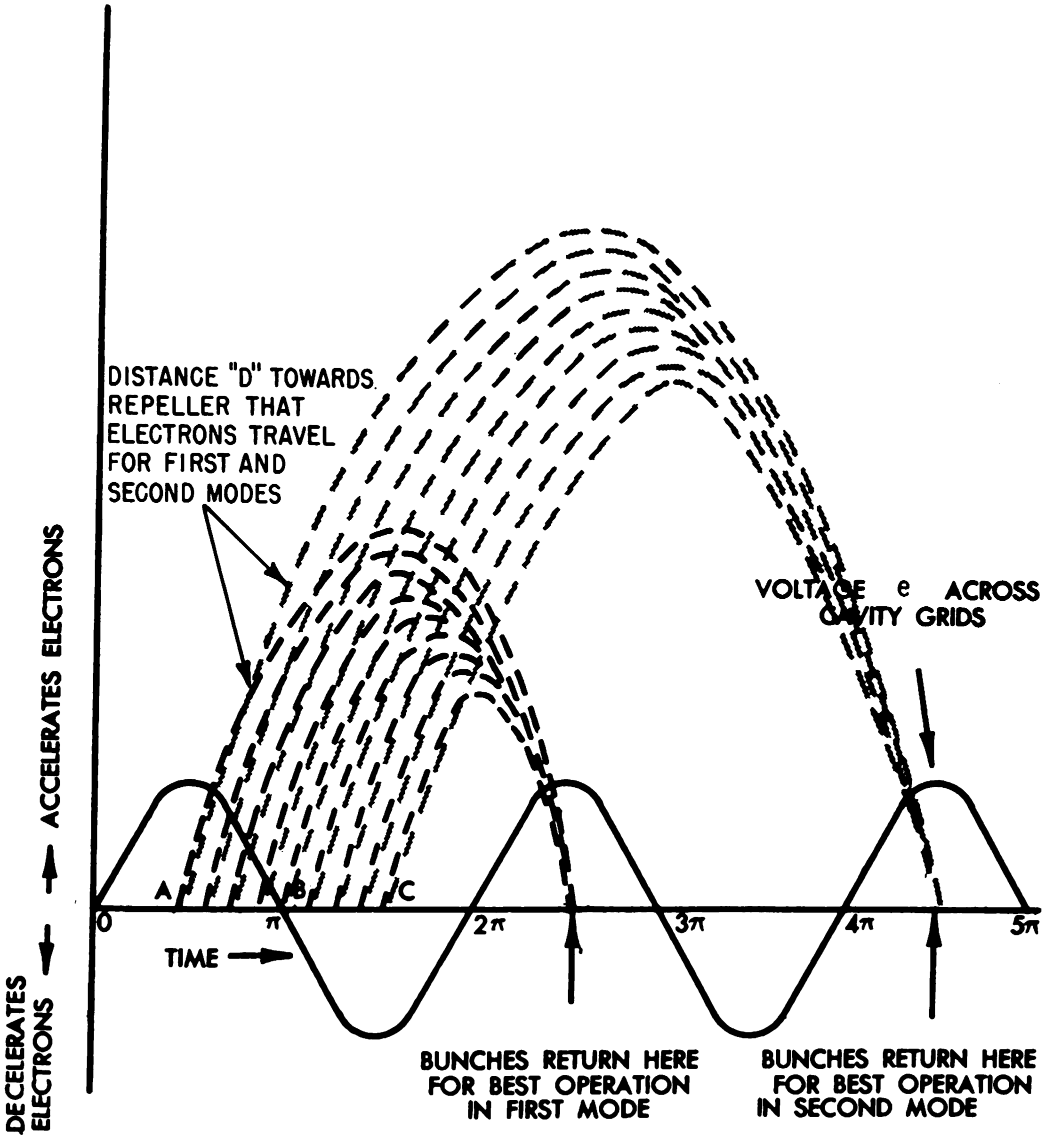
DISTANCE "D" TOWARDS REPELLER THAT ELECTRONS TRAVEL FOR FIRST AND SECOND MODES
VOLTAGE e ACROSS CAVITY GRIDS
ACCELERATES ELECTRONS
DECELERATES ELECTRONS
A
B
C
0
π
2π
3π
4π
5π
TIME
BUNCHES RETURN HERE FOR BEST OPERATION IN FIRST MODE
BUNCHES RETURN HERE FOR BEST OPERATION IN SECOND MODE

Figure 8-38. —Bunching action of a reflex klystron.

orth. In actual practice there are three or four modes" in which it is possible for the reflex-'elocity-modulated tube (klystron) to oscillate. 'he dark lines in the illustration indicate paths f electrons operating in the first mode while ıe light lines indicate paths of electrons operating in the second mode. A third mode is ossible when the average transit time is 2 3/4 ycles, and so forth.

The following shows how the transit time is ontrolled to produce oscillations in the different ıodes. Since the original velocity of an electron epends on the d-c volt voltage E_a, and since the distance that the electron travels before turning back and the speed with which it returns depend upon the difference between E_a and E_r, it is possible to adjust the two voltages E_a and E_r for any of the modes. The voltage E_a is usually fixed in magnitude since varying it produces greater initial velocity. This in turn would cause a farther excursion and a greater return velocity. E_r is made variable since it is not feasible to make E_a variable. For operation in the first mode, the round trip must be completed in the shortest time. This is accomplished by making the repeller plate highly negative. For longer

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time in the interelectrode space, the repeller is made less negative.

Figure 8-39 shows power output and frequency of oscillations as functions of the repeller voltage for three modes of operation. Notice that the frequency at the point of maximum output is the same for all three modes and is the resonant frequency of the cavity. In addition, note that the power outputs for the various modes at the resonant frequency are not the same and that the output is least in the highest mode. This can be explained by examining the factors which limit the amplitude of oscillations and which, in turn, limit the power output.

Power and amplitude limitations are due to overbunching as well as the usual losses in the oscillatory circuit. Overbunching occurs in the following way. As oscillations build up and e becomes greater, the amount of acceleration and deceleration increases. This causes bunching to occur within a shorter period of time, that is, in a time before the electrons reach the grids on the return trip. This tends to reduce the magnitude of oscillations. In the higher modes of oscillations where the bunches are formed more slowly, the electrons are more susceptible to overbunching. The magnitude of e which results in overbunching is therefore lower and oscillations are limited by this action to a lower amplitude than the lower modes of operation.

As shown in figure 8-39, the frequency of oscillations in a reflex klystron is variable to a limited degree in any of the modes of operation by means of varying the repeller voltage. When the repeller voltage is varied, it causes a bunch to return a little sooner or a little later than normal. Off resonance, the amplitude of oscillations decreases by an amount which depends on the Q of the cavity. In this tube the tuning range is small in comparison to the frequency of oscillations and varies somewhat from one mode to another, being greatest in the highest mode. This can be explained from the fact that in the highest mode, bunching and debunching take place at a slower rate and that greater variation from the ideal time of return is possible without debunching, causing the amplitude of oscillations to drop below this usable output level. Another way to look at it is that in the highest mode the interval between leaving the grids and returning is greater, and the change in period represented by a given change in frequency is a smaller portion of the interval. To illustrate, in the third mode the interval before return must be about 2 3/4 cycles. A small

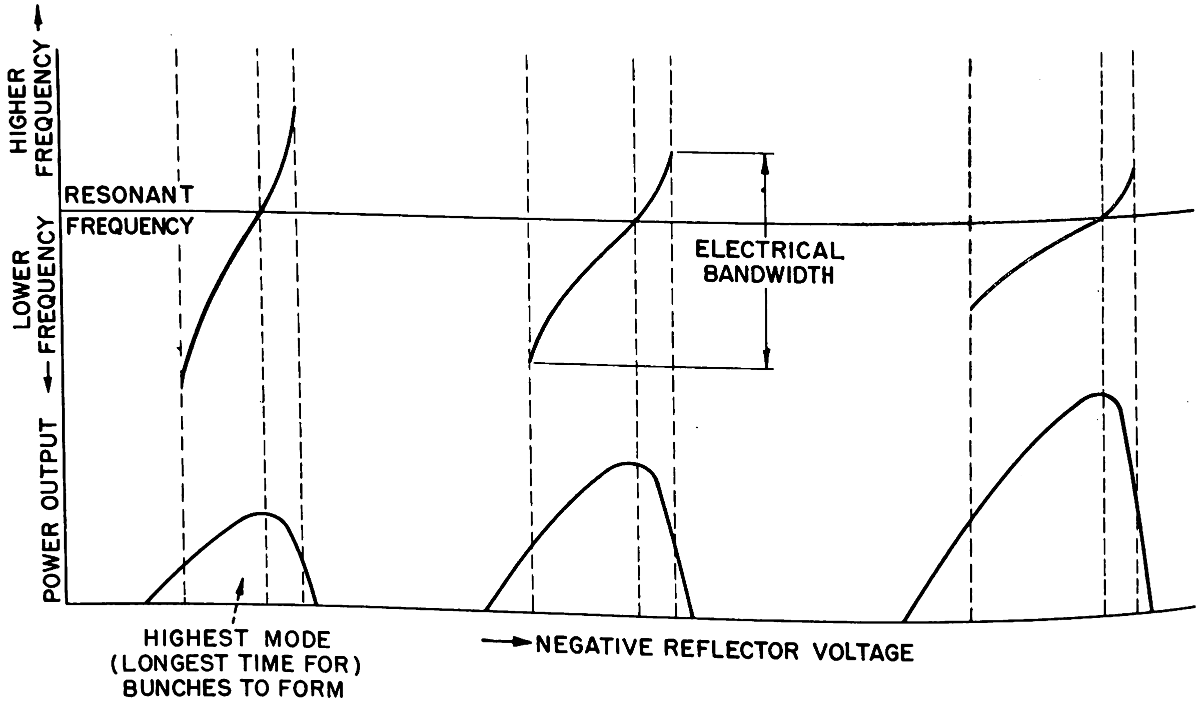

Figure 8-39. —Power output and frequency versus reflector voltage in different voltage modes for a reflex klystron.

hange in the period of e would therefore be only
/4 divided by 2 3/4 or 3/11 as great a portion
f the interval as it would if operation were in
e first mode where the ideal time interval is
/4 cycle.

The band of frequencies which can be ob-
ined by varying the repeller voltage lies be-
ween the half-power points shown in figure
-39. This range of frequencies is known as the
LECTRICAL BANDWIDTH. The output curves
the bandwidth are unsymmetrical about the
aximum output points. This results from the
ct that if E_r is increased, not only does the
nching voltage e decrease and cause bunches
form at a later time, but the repeller voltage
uses a quicker return and the effects of the
o actions add to cause poor bunching at the
ne the electrons return, resulting in a rapid
op in output on the high side of the hump. At
wer voltages, however, even though the bunch-
g voltage e decreases and causes slower
nching, the decreased repeller voltage causes
ater return to the grids so that the two effects
e counteracting and a greater change in re-
ller voltage is possible before the output drops
low the usable level.

The choice of the point and mode of opera-
n is a compromise of several factors. To
gin with, there are three or four modes which
ve the necessary power output. On the whole,
would seem then that the correct choice would
the highest mode, for it gives the largest
ing range. The highest mode, however, is
sensitive to a change in voltage to be well
ulated. A change of one volt may cause a
nge of 0.5 mc. in the 3,000-mc. oscillator.
ce the humps are unsymmetrical, the point
operation is usually chosen a little below the
nt of maximum output. This makes it possible
une above the operating frequency by a greater
ount than if the maximum point were used.

In a radar set, the reflex klystron is usually
d in conjunction with an automatic-frequency-
trol circuit; a circuit which frequently is
d to control the repeller voltage in such a
as to maintain the correct intermediate
quency. The details of the discriminator cir-
and its operation are covered in chapter 5.
p in mind that the frequency of oscillations
rimarily determined by the dimensions of
cavity and that the repeller voltage is effec-
in making small changes in the frequency.
ce, in most reflex klystrons there is a
rse frequency adjustment which varies the
ty size in some way and the repeller voltage
is the fine frequency adjustment. The dimensions of the cavity are changed (fig. 8-40) by a mechanical adjustment.

It is true that the klystron frequency is primarily determined by the size of the cavity. However, once built, the spacing between grids G_1 and G_2 is the controlling factor, and a mechanical adjustment is provided which physically controls their spacing. Moving the grids closer together increases the capacity between them and consequently reduces the output frequency. Although this adjustment may also reduce the overall size of the resonant cavity, its effect is small as compared to the effect of the change of capacitance.

Klystron Thermal Tuning

It has been found advisable in the later types of equipment to operate the klystron's local oscillator at a point of maximum output (klystron tuned for maximum crystal current). This is necessary because the noise output of the local oscillator is at a minimum at this point. Maximum output is obtained when the klystron's cavity is resonant to the output frequency. In order to accomplish this in a practical installation it is necessary that a tuning mechanism be used that will permit remote control of the cavity dimensions of the klystron.

One method of accomplishing this is through the use of a remotely controlled cavity tuning motor. A newer method of remotely tuning the klystron cavity has been incorporated in the design of some of the newer tubes. In this type tube the tuning mechanism is a part of the klystron. In one tube of this type the upper section contains a triode. (See fig. 8-40.) The plate of this triode changes in length in accordance with the temperature of the plate. This temperature varies in accordance with plate current.

The variations of the triode's plate length are impressed through mechanical linkage on the cavity of the klystron. Thus, by controlling the grid voltage of the triode, and in turn its plate current, it is possible to vary the dimensions of the cavity in the klystron. This method of tuning is known as THERMAL TUNING.

In some tubes the triode is replaced by a diode. This diode has a control tube connected in series with it and a B supply. By varying the bias on the control tube it is possible to control the diode's plate current and this in turn varies the dimensions of the klystron's cavity.

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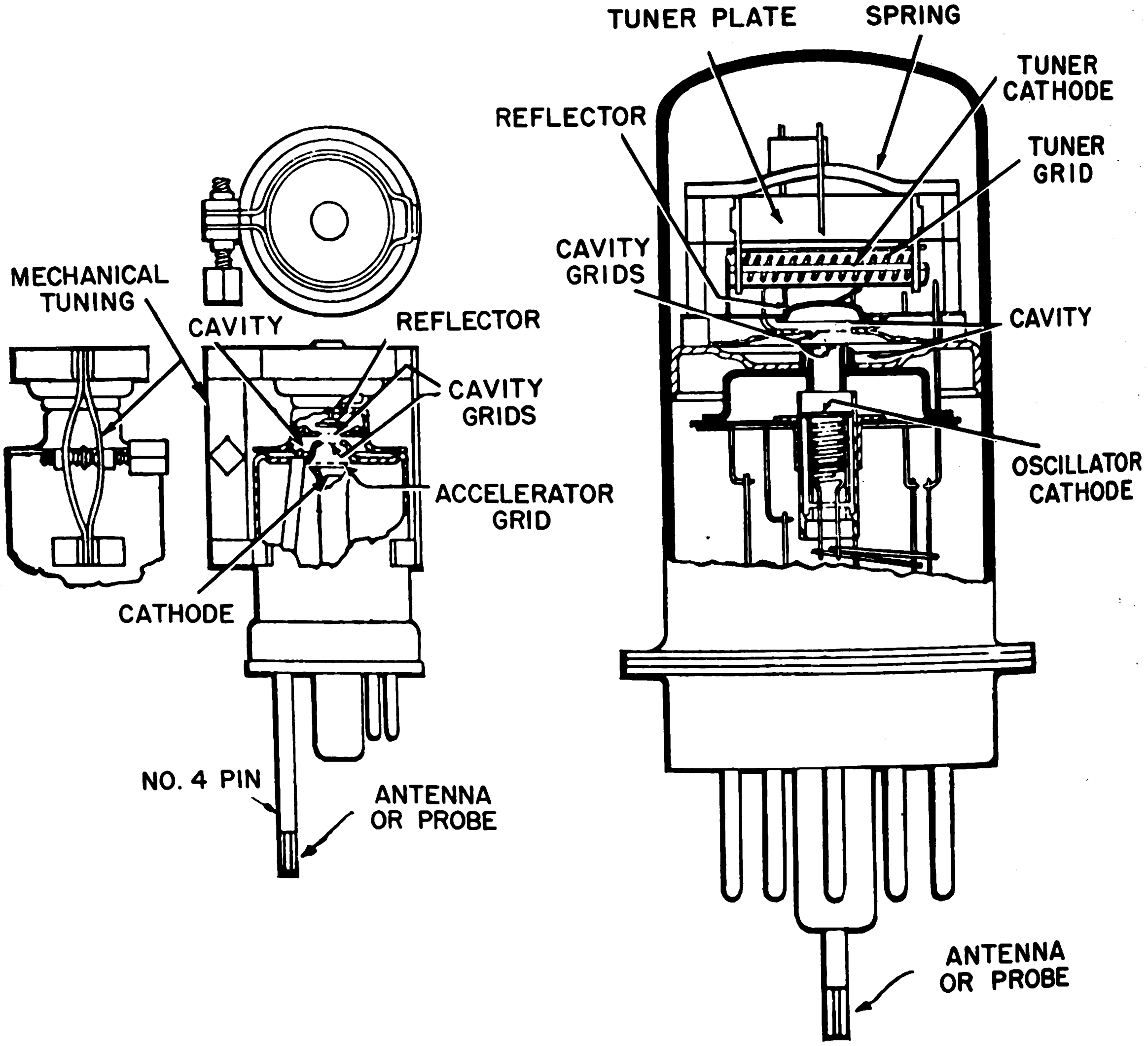

Figure 8-40. —Construction of typical reflex klystrons.

INPUT CIRCUITS OF UHF RECEIVERS

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A careful choice of input circuit is very important, because it is in this portion of the receiver that noise has the greatest effect on receiver sensitivity. In the microwave region, a low noise figure is obtained most readily by applying the received signals directly to a mixer circuit employing a crystal. In the UHF range it is usually advantageous to precede the vacuum tube mixer by one or two stages of radio-frequency amplification.

Vacuum tubes have several advantages over crystals in the input circuits of a radar receiver. Because crystals are delicate, they must be protected extremely well by the TR device in order to avoid burnout during transmission. Vacuum tubes, on the other hand, are able to withstand relatively large amounts of transmitter power. Mixer circuits employing triodes also have a somewhat higher conversion gain than crystal mixers, although they generate more noise. The effect of the increased noise may be offset at ultrahigh frequencies by preceding the triode mixer by one or more stages of radio-frequency amplification—the noise figure of a

de is appreciably less when used as an am-
er than when used as a mixer.

Jnfortunately, the tubes that are available
operation in the microwave region generate
xcessive amount of noise and are therefore
suitable for the input circuits of microwave
eivers. Consequently, use of vacuum tube
t circuits is restricted to receivers that
ate in and below the UHF range. First,
um tube input circuits are discussed; and
nd, several forms of crystal-mixer input
uits are discussed.

The input circuits of UHF receivers usually
loy disk-seal triodes and are frequently
ected to form a grid-return type of circuit.
RF amplifier employing a disk-seal tube in
rid-return circuit is very stable and has
little tendency to oscillate, the only feed-
path being through the extremely low
-to-cathode capacitance of the tube. Pen-
s are available for operation in the UHF
e, but they generally have a higher noise
e than triodes and are therefore less suit-
in radar or other applications when a high
ee of sensitivity is required.

n VHF receivers that operate at 200 mega-
es or below, the tuned circuits of the input
es are composed of lumped inductances and
citances. Often physical capacitors are un-
ssary, the inductors being made to resonate
the tube and wiring capacitances. In the
on of 1,000 megacycles the lumped-
meter resonant elements are replaced by
y resonators.

n example of an input circuit of a receiver
operates in the vicinity of 1,000 mega-
s is given in figure 8-41. The circuit con-
of a single stage of radiofrequency ampli-
ion, a local oscillator, and a mixer.
house tubes and coaxial-line resonators
employed in each unit, and connections be-
units are made by means of short sections
axial cable. The lighthouse tubes are shown
ted in their respective tuners in (A) of the
e.

ie RF amplifier is similar in construction
lighthouse-tube oscillator shown in figure
nd the local oscillator in figure 8-41. The
najor difference between the RF amplifier
he local oscillator shown in figure 8-41 is
n the amplifier the middle cylinder of the
is not cut away at the grid terminal of the
As shown in the local-oscillator section
ure 8-41 (A), the cutaway section of the
line provides the extra coupling needed in
the oscillator between plate and cathode lines. Since there is no cutaway section in the RF amplifier's grid line, the plate and cathode circuits are isolated except for the small interelectrode capacitance between the plate and cathode of the tube.

The plate supply voltage is conducted to the plate terminal of the amplifier tube V_1 by means of an insulated wire which passes through the innermost coaxial cylinder. This cylinder, which serves as one conductor of the plate line, is coupled to the plate terminal through capacitor C_1 in order that the tuner may be operated at ground potential. Inductor L_1 serves as a choke to prevent RF signals from entering the power supply. The middle cylinder of the tuner connects directly to the grid terminal, and the outer cylinder fits over the shell of the tube, which is grounded. All cylinders are connected together by the shorting plungers in the plate and cathode lines. A bypass capacitor within the tube provides an RF connection between shell and cathode, and cathode bias voltage is developed across C_{k1} and R_{k1} in parallel between the cathode pin and ground. Input signals are coupled into the cathode-to-grid line by means of a probe, and a coupling loop is used to take the amplified RF signals from the plate-to-grid line.

An RF equivalent circuit of the amplifier, in which the plate and cathode lines are replaced by parallel L-C circuits, is shown in the upper left portion of figure 8-41 (B). Observe that the equivalent circuit is drawn so as to emphasize the grid-return aspect of the amplifier. The plate line, represented by L_{p1} and C_{p1} in the figure, is adjusted to resonate with the plate-to-grid capacitance C_{gp} of the tube at the frequency of the incoming signal, and the cathode line in parallel with C_{gk} is adjusted very nearly to the frequency of the incoming signals. Actually, the cathode line is made slightly inductive in order that any feedback voltage supplied through the small plate-to-cathode capacitance C_{kp} (approximately 0.05 $\mu\mu$f) will have a phase opposite to that required to start oscillations. Thus the cathode-line length is somewhat less than a quarter wave at the signal frequency.

Because the output coupling loop of the amplifier is located near the shorting plunger in the plate line, the output coaxial cable is shown as a tapped connection to L_{p1} in figure 8-41 (B). The plate line thus acts as a resonant transformer to change the low input resistance of the cable (approximately 50 ohms, since the cable

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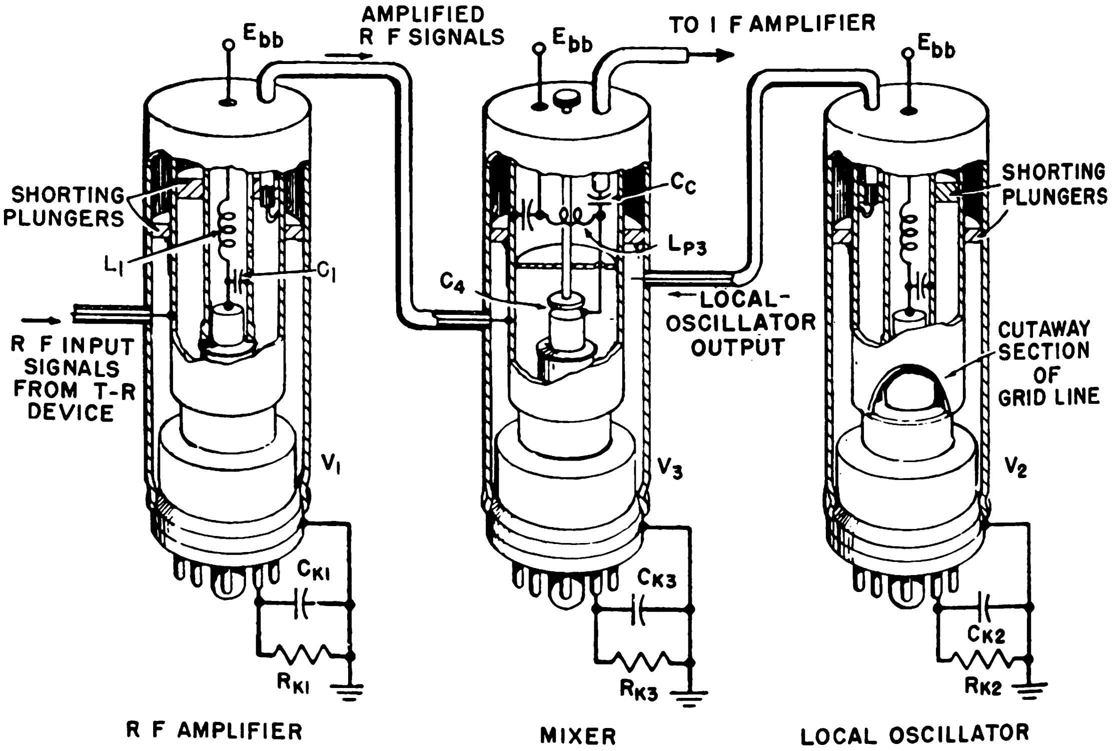
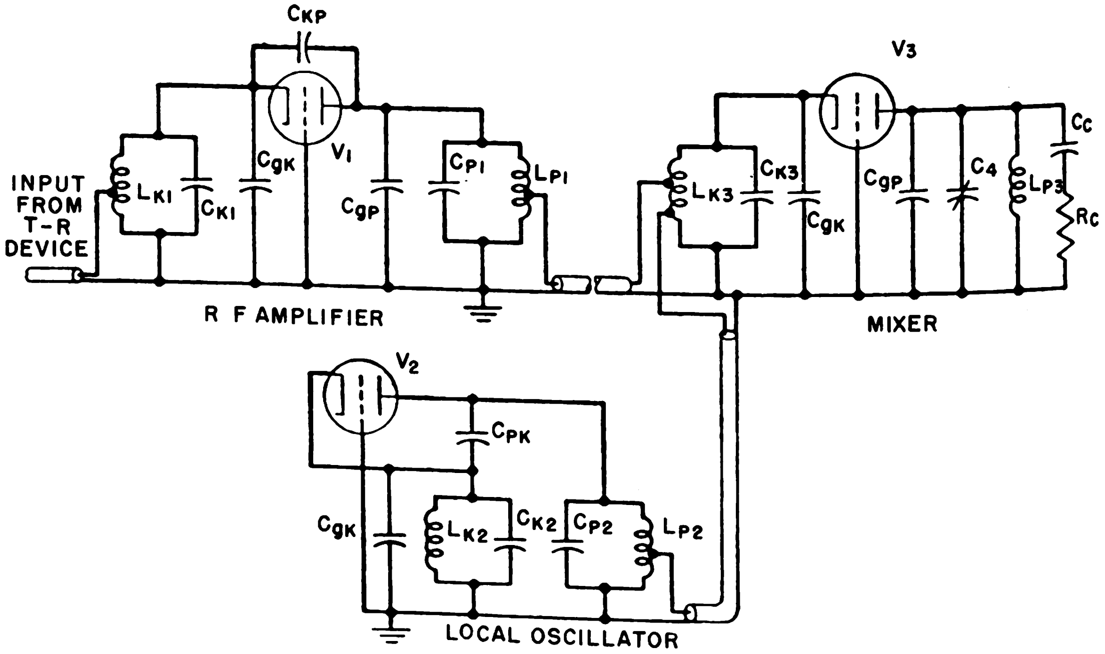


(A) CIRCUIT LAYOUT



(B) RF EQUIVALENT CIRCUIT

Figure 8-41.—Example of an input circuit of a UHF receiver.

usually matched at the far end) to a higher istance across the entire resonant circuit. e value of load resistance across the resonant cuit is governed primarily by the bandwidth uired for the amplifier. Since no provision made for tuning the amplifier during its mal operation, the bandwidth must be wide ugh to pass received signals despite slight nges in the transmitted frequency.

The tuned cathode circuit is loaded by the ut resistance of the amplifier inparallel with esistance representing grid-loading effects l tuned-circuit losses. The net resistance is tched approximately to the characteristic istance of the input line by tapping the input le to a point near the shorted end of the hode line. The tap location is chosen for op- um signal-to-noise ratio and results in a istance termination for the input line which slightly more than its characteristic re- tance.

The local oscillator, shown at the right in ure 8-41 (A), is similar in construction to RF amplifier except that the grid cylinder partly cut away near the local-oscillator tube. us C_{pk} in the oscillator equivalent circuit . 8-41 (B)) includes both the plate-to- hode capacitance of the tube and the external ipling capacitance resulting from the opening the grid line. All cylinders of the oscillator er, like those of the RF amplifier, operate ground voltage, and the cathode is maintained a positive potential with respect to ground ause of the bias voltage developed across C_{k2} arallel with R_{k2}.

The local oscillator is tuned in accordance n the principles discussed for the lighthouse- e oscillator in the early part of this chapter. plate-line length is the primary control for uency and, in fact, constitutes the main tun- control for the receiver. Tuning is accom- hed by means of a knob or dial connected to plate-line shorting plunger through a mech- m not shown in the figure. The cathode- length governs the magnitude and phase of voltage fed back to the cathode circuit from plate circuit and must be adjusted so that a citive reactance appears between grid and ode at the oscillation frequency. At fre- icies in the neighborhood of 1,000 megacycles second, it is mechanically feasible to choose lengths so that each line employs its lowest mode of resonance. Thus the cathode line is approximately one-quarter wave at the oscillator frequency, and the plate line is less than a quarter wave.

Power coupled from the plate line of the local oscillator is applied, together with echo signals from the RF amplifier, to the cathode line of the mixer tube V_3. A component of current at a frequency equal to the difference between the local-oscillator and echo-signal frequencies is produced in the plate circuit of the mixer, and the plate circuit is tuned to this difference frequency.

The mixer tuner differs from the local-oscillator and RF amplifier tuners in that it employs a coaxial-line cavity only between cathode and grid, lumped parameters being used in the plate circuit. The tuned-plate circuit consists of inductor L_{p3} in parallel with inter-electrode capacitance C_{gp}, the series combination of C_c and the input resistance R_c of the output line, and the variable capacitance C_4 formed by a movable metallic disk near the plate terminal of the tube. The capacitance of C_4 is varied by changing the disk position by means of a rod which passes through the end of the tuner.

The various components comprising the tuned-plate load of the mixer are illustrated in figure 8-41 (B). Because input signals are applied between grid and cathode of the mixer and the intermediate-frequency signals appear between grid and plate, the equivalent circuit is represented as a grid-return circuit. From the equivalent circuit it may be seen that the variable capacitor C_4 serves to tune the remaining plate-circuit elements to resonance at the intermediate frequency. Placing capacitor C_c in series with the output cable isolates the cable from the power supply voltage and causes the low input impedance R_c of the cable to appear as a higher resistance across the entire circuit.

The receiver input circuit of figure 8-41 (A) requires that the interconnecting cable between RF amplifier and mixer be short. Otherwise appreciable attenuation of received signals will occur in the cable and cause noise generated in the mixer to become important. If cable loss is excessive, it may become necessary to employ a second stage of RF amplification in order to maintain the signal level well above the noise level of the mixer.

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CRYSTAL MIXERS

Single-Ended Crystal Mixers

In microwave receivers, amplification of received signals at the carrier-frequency level is generally undesirable because of the rather large amount of noise generated by available microwave-amplifier tubes. Echo signals of a microwave radar system, after passing through the TR device, are therefore applied directly to the crystal mixer. A voltage from a local oscillator, usually a klystron, is applied to the mixer simultaneously with the echo signals, and signals at the intermediate frequency are derived at the mixer output terminals.

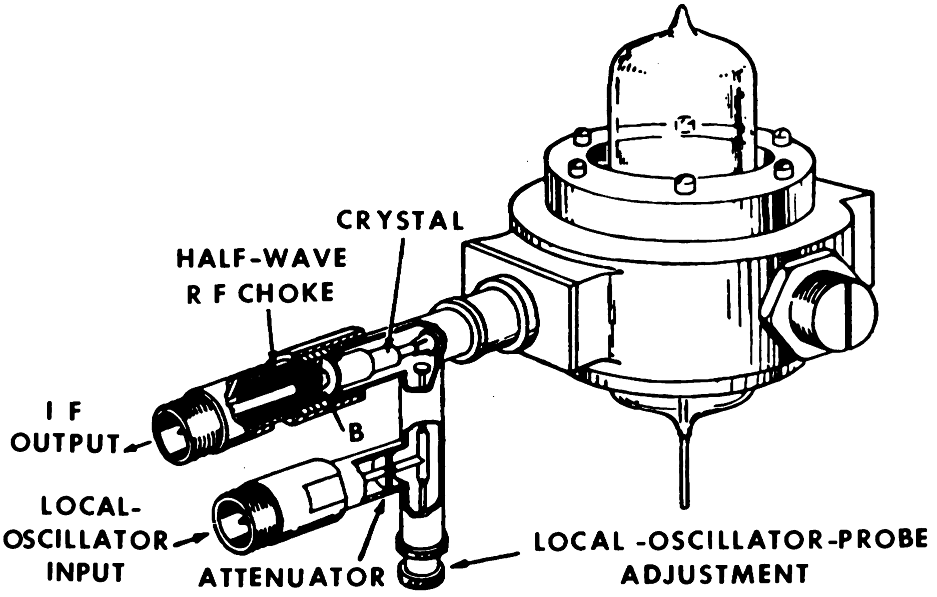
The important features of a 10-cm. mixer employing coaxial-line sections are given in figure 8-42 (A). Echo signals are coupled into the transmission-line section between TR cavity and crystal by means of a coupling loop which penetrates a short distance into the cavity. The crystal fits snugly into the inner conductor of the line and is held concentric with the outer conductor by means of a dielectric bead. The local-oscillator signal is introduced into the mixer assembly by means of a coupling probe located approximately a quarter wave (at the local-oscillator frequency) from the coupling loop in the TR cavity. A high impedance in the direction of the cavity is thus presented to the local-oscillator signal at the probe. The strength of the local-oscillator signal at the crystal may be changed by varying the distance the probe extends into the main line. Power from the local oscillator is conducted to the probe via a section of transmission line.

Connection between the crystal and inner conductor of the line section carrying IF signals is provided by a spring contact (fig. 8-42(A)). The half-wave RF choke appearing on the IF side of the crystal provides an electrical short circuit for radiofrequency signals at point B. The d-c return path required for crystal current is provided at the RF end of the mixer assembly by the TR coupling loop and at the IF end by the shunt-inductance element located in the grid circuit of the input IF amplifier stage.

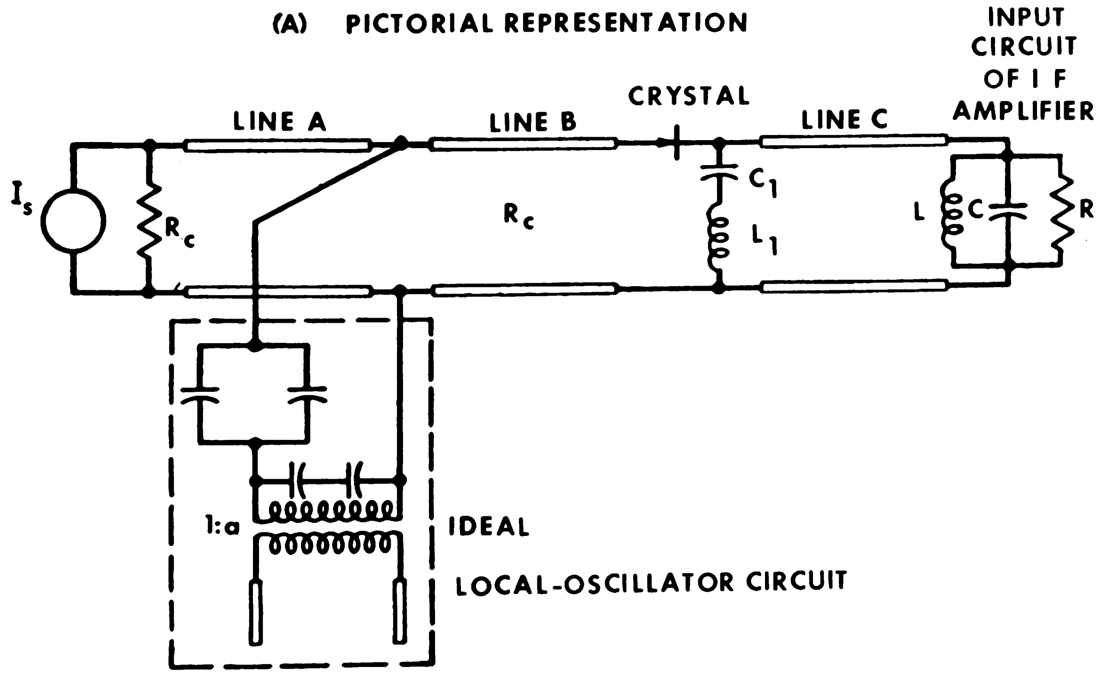
A two-wire equivalent circuit of the mixer is given in figure 8-42 (B). If small losses in the RF line and TR cavity are ignored, the portion of the RF transmission system between antenna and output terminals of the TR cavity may be represented by a signal-current source I_S in shunt with the characteristic resistance R_C of the transmission line. Because the local oscillator is loosely coupled to the main line, negligible admittance appears in shunt with the lines A and B in figure 8-42 (B). Elements L_1 and C_1 represent the RF choke at the IF end of the crystal and are series resonant at the echo-signal frequency. Hence line B is terminated by the crystal at the echo-signal frequency. For maximum receiver sensitivity it is important that essentially all the echo power available at the TR device be transferred to the crystal. The crystal should therefore present a matched-load termination to the main-line section. Fortunately 10-cm. crystal units, when operated with 5/16-inch 50-ohm coaxial lines, provide essentially a matched RF load for the line. An impedance-changing device between crystal and TR cavity is therefore unnecessary.

Because the local oscillator is loosely coupled to the main line containing the crystal, an appreciable mismatch of impedance exists on the local-oscillator line at the coupling probe. A large impedance mismatch is in general undesirable because of the wide variations in local-oscillator load impedance (and hence power output) that result when the oscillator frequency is varied. A good impedance match is particularly important if the line between local oscillator and probe is long. To insure a relatively constant load impedance for the oscillator, a resistance-disk type of attenuator is oftentimes inserted in the local-oscillator line, as shown in figure 8-42 (A), in order to terminate the line section between oscillator and disk in its characteristic resistance. An alternative to the resistance disk is a piece of lossy cable which may be inserted between local oscillator and mixer assembly. (NOTE: Lossy cable uses resistance wire for the center conductor. An example of lossy cable is RG-21/U.)

Oftentimes mixer assemblies include, in addition to the circuit that supplies IF echo signals, a separate mixer for generating IF signals for the automatic-frequency-control circuit. An example of a 3-cm. mixer assembly of this type is shown in figure 8-43 (A). Local-oscillator power and RF echo signals from the TR cavity are coupled into waveguide 1, which serves as the echo-signal channel. A crystal extends between top and bottom walls of the guide, the lower end of the crystal being isolated from the guide by means of a dielectric washer. Echo-signal voltages in the intermediate-frequency band appear between the lower end of the crystal and the waveguide and are conducted to the



(A) PICTORIAL REPRESENTATION



(B) AN EQUIVALENT CIRCUIT

Figure 8-42.—A 10-cm. mixer.

circuit of the IF amplifier, usually over
ial cable.

veguide 3 is similar in construction to uide 1 and serves as the AFC channel. from the local oscillator and a small amount of the transmitter power are applied to the AFC crystal, and IF signals for the AFC circuit are derived at the lower end of the crystal mount, as before. Attenuation between the main guide and guide 3 is provided by means of

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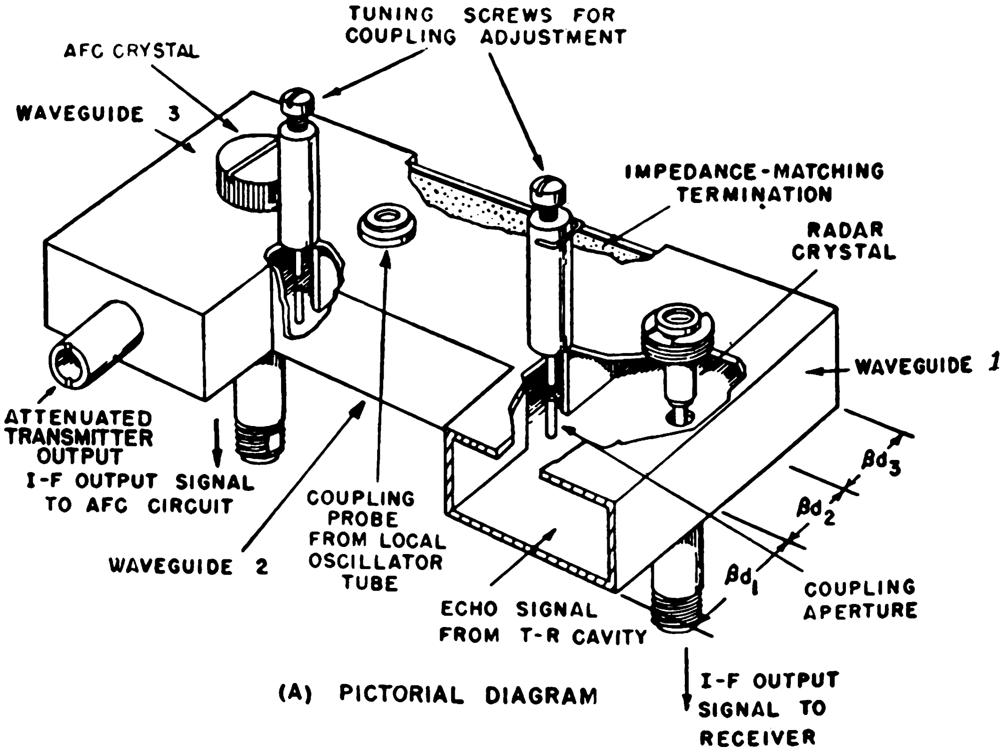
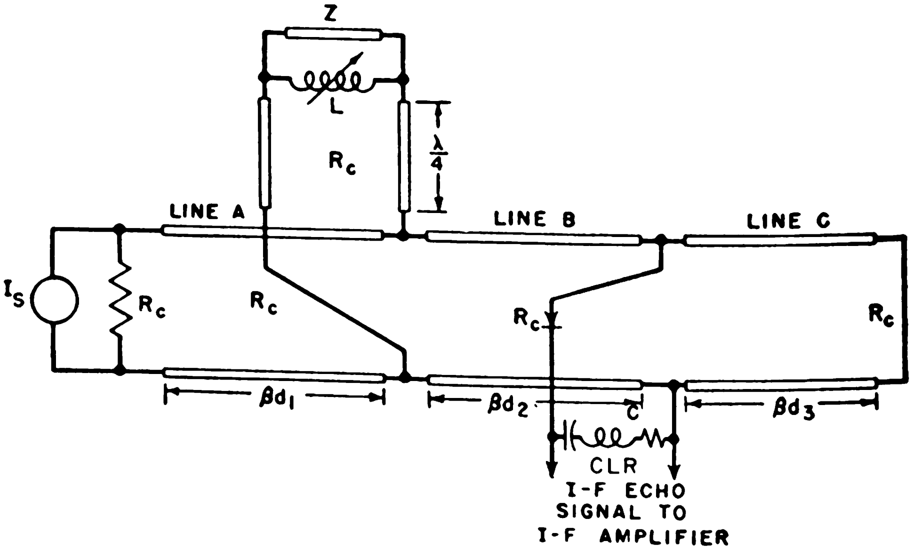

TUNING SCREWS FOR COUPLING ADJUSTMENT
AFC CRYSTAL
WAVEGUIDE 3
IMPEDANCE-MATCHING TERMINATION
RADAR CRYSTAL
WAVEGUIDE 1
ATTENUATED TRANSMITTER OUTPUT
I-F OUTPUT SIGNAL TO AFC CIRCUIT
COUPLING PROBE FROM LOCAL OSCILLATOR TUBE
WAVEGUIDE 2
βd_3
βd_2
βd_1
COUPLING APERTURE
ECHO SIGNAL FROM T-R CAVITY
I-F OUTPUT SIGNAL TO RECEIVER

(A) PICTORIAL DIAGRAM



(B) AN R-F EQUIVALENT CIRCUIT OF ECHO-SIGNAL CHANNEL

Figure 8-43. —A 3-cm. mixer.

a circular-waveguide section operating below cutoff. Sometimes a disk type of attenuator is included in the circular section to reduce further the amount of transmitter power reaching the mixer assembly.

The local-oscillator tube is mounted above waveguide 2 in a manner that permits the local-oscillator output probe to extend a short distance into guide 2. The coupling probe may be displaced slightly from the center of the transverse is of the guide in order to obtain a load im- dance for the oscillator which yields a reason- ly uniform power output over the tuning range.

Local-oscillator power is coupled from guide into guides 1 and 3 through coupling apertures cated in the side walls of the guides. A match- g post and tuning screw extending from top d bottom walls of the guides at the aperture cations serve to regulate the amount of local- cillator power coupled to the mixer circuits.

For optimum performance of the radar sys- m, the echo-signal channel of the mixer should ovide a matched-load impedance to the wave- ide transmission system. The elements that termine the mixer input impedance are shown the equivalent circuit of figure 8-43 (B). The uivalent circuit is derived by dividing wave- ide 1 into three sections of lengths βd_1, βd_2, d βd_3 and representing the sections by uivalent lengths of transmission lines (lines B, and C in fig. 8-43 (B)). The signal-current nerator I_s in shunt with R_c in the equivalent rcuit accounts for the portion of the RF system tween antenna and mixer. The coupling aper- re between local-oscillator and mixer guides uides 1 and 2) is represented by a variable in- ictance L, and in shunt with L is an impedance which accounts for the impedance seen in the rection of the local-oscillator guide. The rallel combination of L and Z terminates a arterwave section of line which is in shunt with ies A and B. At the echo-signal frequency, the pedance of L and Z in parallel is maintained iall enough in comparison with the charac- ristic resistance of the quarter-wave line to ike the input impedance of the quarter-wave ction extremely high and hence the amount of io-signal power entering the local-oscillator ide extremely small.

The crystal is located at the junction of lines and C, as shown in figure 8-43 (B), and across crystal output terminals is a series R-L-C cuit. The counterpart of the R-L-C combina- n in figure 8-43 (A) is an RF choke in the IF put lead of the mixer. The choke prevents signals from entering the input circuit of IF amplifier.

The length of shorted-end line C must be h that the input admittance of line C, in shunt h the RF admittance of the crystal, provides entially a matched load for line B. Varying length of line C changes the susceptance component of the total admittance at the crystal location. A length of approximately $\lambda/4$ is usually preferable in order to minimize changes in admittance with frequency.

Balanced Crystal Mixers

The noise introduced into the input circuit of a microwave receiver by the local oscillator may be reduced appreciably through use of a balanced mixer. An input circuit of this type employs two crystal mixers connected so that the local-oscillator voltages applied to each crystal are in phase and the echo-signal voltages at each crystal are 180 degrees apart in phase. As explained below, this method of circuit connection causes the IF components of local-oscillator noise to cancel in the IF amplifier input circuit and the IF components of the signal to add. Because of their ability to suppress local-oscillator noise and because of certain additional advantages to be discussed later, balanced mixers are oftentimes preferable to single-ended mixers. They are presently finding wide use in microwave radar systems.

The basic principles of a balanced mixer may be explained from the diagram of figure 8-44, which shows two crystals mounted a half wavelength apart (at the signal frequency) between conductors of a coaxial-line section. Each crystal is located a quarter wave from the nearer end of the line, and the local-oscillator signal is probe-coupled to the line at a point

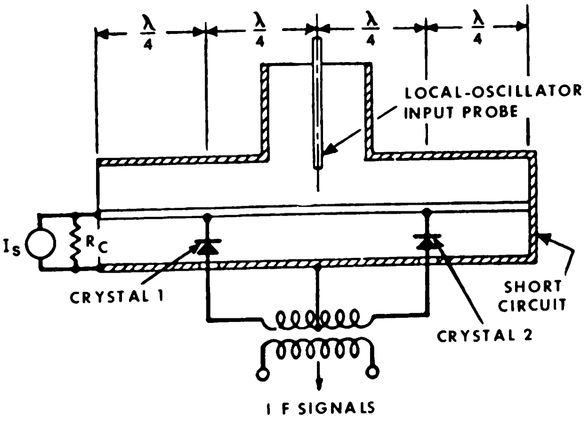


Figure 8-44. —Coaxial line balanced-mixer circuit.

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midway between the crystals. The output terminals of the crystals are connected to an IF transformer, the primary winding of which is balanced to ground. The signal-current generator I_s in shunt with resistance R_c accounts for signals entering the mixer from the TR device.

The local-oscillator coupling probe gives rise to two waves traveling in opposite directions in the coaxial line. Assume that at the local-oscillator frequency the TR device presents a short circuit to the local-oscillator wave traveling to the left in figure 8-44, and that the crystals have identical RF impedances equal to twice the characteristic resistance of the line. Then equal-amplitude, in-phase, local-oscillator voltages appear at the crystals. Because of the half-wave spacing between crystals, the RF echo-signal voltages at the crystals are also of equal amplitude but are 180 degrees apart in phase. An in-phase relation between local-oscillator and echo-signal voltages produces an IF signal voltage of one phase, and a 180-degree phase relation between local-oscillator and echo-signal produces an IF signal voltage of opposite phase. Thus the two IF echo-signal voltages add in the balanced input circuit of the IF amplifier. Because the noise that accompanies the local-oscillator signal produces voltage components that bear the same phase relation to the local-oscillator voltage at each crystal, the corresponding IF components of noise at the output of each crystal are in phase and hence produce no resultant noise voltage across the IF transformer.

In order to realize full benefit from use of a balanced-mixer circuit, the crystals should have similar RF impedances as assumed above, and in addition they should have similar conversion gains. Under these conditions of operation, only one-half the available RF power is applied to each crystal, but since the IF signal powers from the crystals add together, the total IF power is the same as that obtained from a single-ended mixer. Since IF components of local-oscillator noise are completely eliminated, maximum reduction in overall noise figure is obtained.

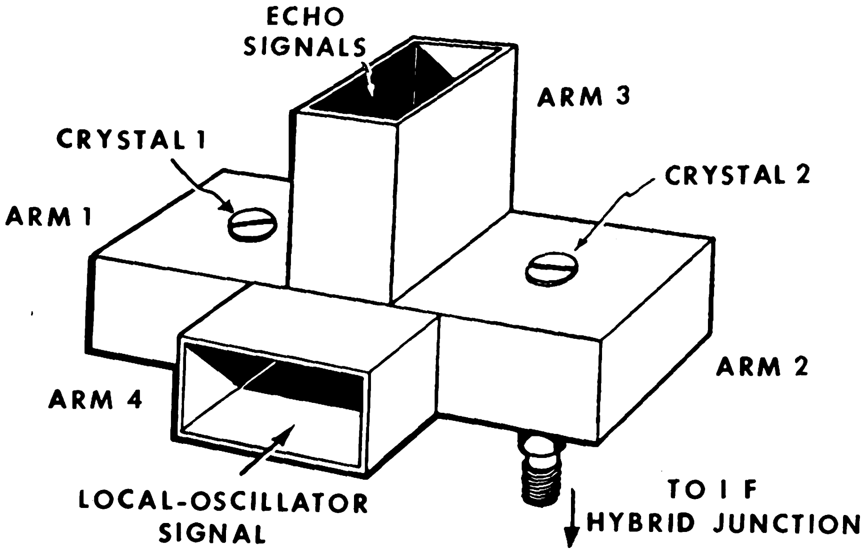
An unbalance in conversion gain yields an unbalance in the IF signal voltages obtained from each crystal and also an unbalance in the IF components of local-oscillator-noise voltages at the crystal output terminals. However, since the IF signal voltages are additive in the crystal output circuit and the local-oscillator-noise components are subtractive, small unbalances in conversion gains do not seriously affect the overall receiver noise figure.

More important are the effects of a difference in the RF admittances of the crystals. An unbalance of this type causes both the echo-signal power and the local-oscillator power to divide unequally between the two crystals. As a result, the IF signal power obtained from the mixer is appreciably reduced, and in addition the IF components of local-oscillator noise are prevented from canceling completely in the IF input circuit. Crystals intended for use in a mixer constructed as shown in figure 8-44 must be carefully selected on the basis of equal RF admittances in order to insure most satisfactory operation.

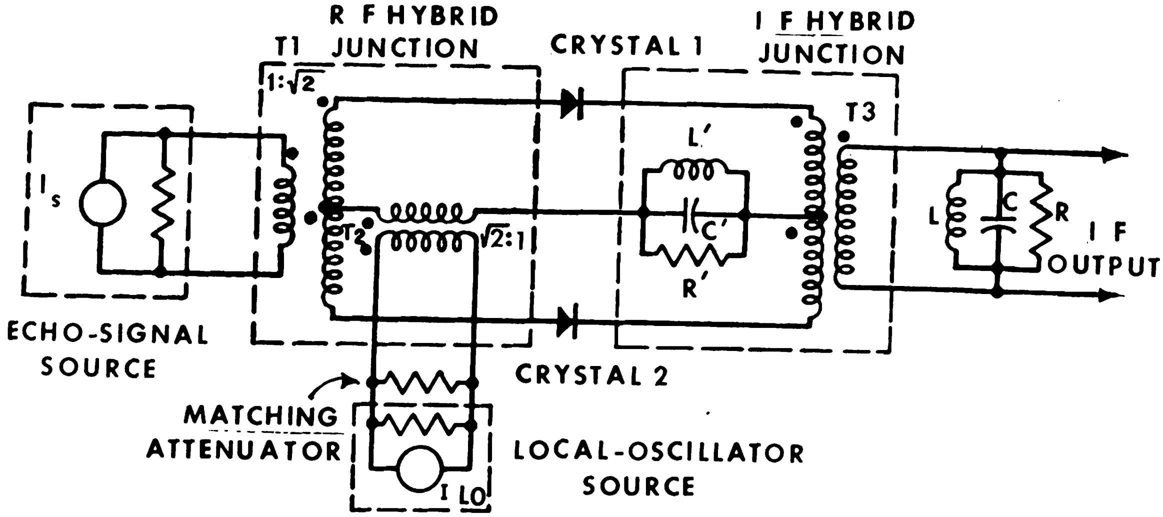
A balanced mixer that is superior in several respects to the coaxial-line mixer just described is shown in figure 8-45 (A). This mixer employs a waveguide hybrid junction of the type discussed in chapter 7; this junction is often called a MAGIC T. Crystals are located in one pair of entries (arms 3 and 4). Usually in a mixer of this type the input circuit of the IF amplifier is also arranged in the form of a hybrid junction. Details of connections of the IF amplifier input circuit, together with the ideal-transformer equivalent circuit of the waveguide junction are given in the right-hand block of figure 8-45 (B). The parallel circuit comprising L, C, and R is tuned to the intermediate frequency and the impedance of the parallel combination of L', C', and R' is made equal to the conjugate of the IF impedance appearing between the terminals to which L', C', and R' are connected.

Ideally the two crystals should be alike. Furthermore, all RF impedances should terminate the entries of the RF hybrid junction in matched loads, and all IF impedances should similarly terminate the entries of the IF hybrid junction. Then, because of the properties of a matched hybrid junction, local-oscillator signals at the crystals are equal in amplitude and in phase, and echo signals at the crystals are equal in amplitude and 180 degrees apart in phase.

The IF components of signals from the crystals are applied in push-pull to ideal transformer T_3 and appear across L, C, and R but not across L', C', and R'. The IF components of noise, on the other hand, are in effect applied between end terminals of T_3 in parallel and appear across L', C', and R' but not across the IF output terminals. Local-oscillator noise is thus



(A) PICTORIAL DIAGRAM



(B) EQUIVALENT CIRCUIT

Figure 8-45. —Balanced mixer employing hybrid junctions.

ressed completely. Because the RF hybrid ion is matched, the total available power the echo-signal and local-oscillator arms es equally between the two crystals. As in coaxial-line mixer of figure 8-44, the IF r from each crystal is one-half the available signal power times the conversion gain G crystal. Since IF power from each crystal livered at the IF output terminal, the total IF output is the product of the echo-signal power and G, as before.

Ordinarily, in single-ended mixers and in the coaxial-line balanced mixer (fig. 8-44), the local oscillator must be loosely coupled to the mixer in order to prevent an appreciable amount of echo-signal power from entering the local-oscillator circuit. As a result, the local oscillator must generate much more power than

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is actually needed for mixer operation, the excess power being dissipated in an impedance-changing device located in the local-oscillator circuit. Because in a hybrid-junction mixer the echo-signal and local-oscillator arms are decoupled, there is no tendency for echo signals to enter the local-oscillator circuit, and hence there is no need for loose coupling between local oscillator and mixer. A local oscillator with relatively low-power output can therefore be used, the only power necessary being that which is needed to drive the crystals. Actually most local oscillators are capable of generating more than the minimum power required, so that a dissipative attenuator can be inserted in the local oscillator in order to insure a matched termination for the arm. Such an attenuator is desirable, as will be seen later.

Decoupling between echo-signal and local-oscillator arms also means that there is no tendency for local-oscillator power to enter the echo-signal arm. Rejection of local oscillator signal by the echo-signal arm is particularly advantageous in systems employing a broadband TR device which would allow local-oscillator power to pass through and be radiated by the antenna.

Another advantage of the hybrid-junction mixer is that its operation is less sensitive to differences in the RF impedance of the crystals than is the balanced coaxial-line mixer. Because the two crystal arms are decoupled, any RF power reflected from one crystal cannot reach the other crystal. All the reflected power is directed into the echo-signal and local-oscillator arms and absorbed by the matched terminations. Thus the amount of RF power delivered to one crystal is independent of the RF impedance of the other.

If a mismatch should exist in either the echo-signal or local-oscillator arm, a reflection of an RF signal arriving at the mismatched termination will occur, and the signal reflected from the termination will enter the two crystal arms. Under these circumstances, the two crystal arms are not completely decoupled. At the echo-signal frequency a mismatch in the echo-signal and local-oscillator arms in unlikely because in general the TR device provides a matched load for the echo-signal arm and, as indicated above, a matching attenuator can normally be inserted in the local-oscillator arm.

In general, if the crystals provide an impedance match at the echo-signal frequency, they do not yield a perfect match at the local-oscillator frequency. This mismatch is unimportant, since the reflected power will be absorbed in the echo-signal and local-oscillator arms. The attenuator in the latter arm serves to prevent the returned signal from reacting on the oscillator. Should the echo-signal arm not provide a matched termination for the returned local-oscillator signal, further reflection of the signal will occur and the balance of local-oscillator power at the crystals will be further upset. The effect of such an unbalance is to change the conversion gains of the crystals slightly, but usually the change is negligible even with moderate amounts of mismatch at the local-oscillator frequency.

Use of the hybrid-junction type of IF input circuit shown in figure 8-45 (B) insures suppression of local-oscillator noise despite unbalance in the IF impedances of the crystals. When all entries of the IF hybrid junction are terminated in a load that is the conjugate of the impedance the load faces, the two crystals, constituting one pair of entries, are decoupled and the two resonant circuits, constituting the other pair, are also decoupled. If the resonant-load entries remain matched, the amount of IF signal power coupled from one crystal to the output terminals is independent even if the IF impedance of the other crystal does not match the arms. Furthermore, the IF components of noise cancel in the output circuit independently of the IF crystal impedance as long as the crystals develop equal IF noise voltage. The IF components of noise appear only across the L', C', and R' arm. If crystals are tested for equal conversion gains while loaded by the conjugate of the IF impedance of a typical crystal, equal IF noise voltages can be expected when the crystals are employed in the circuit of figure 8-45.

Terminating the IF output entry in a matched load does not in general insure minimum noise figure. Mismatching the output entry in order to minimize the noise figure alters the load for the push-pull IF echo signals and thus reduces the echo-signal power delivered to the load but does not alter the load for the IF components of noise which are applied to T_3 in parallel. The local-oscillator noise-suppression property of the mixer is therefore retained.

QUIZ

The hybrid junction mixers
a. cancel local oscillator noise completely
b. reinforce the IF
c. provide better signal-to-noise ratio
d. are more fragile than other types

The mixer stage of a radar receiver is a
a. germanium crystal
b. quartz crystal
c. vacuum tube
d. linear device

RF amplification of the received signal, prior to application to the crystal mixer, is not feasible because of the
a. instability of the magnetron
b. instability of the klystron
c. instability of the automatic frequency control circuit
d. inherent noise characteristics of microwave amplifiers

In a magnetron, electrons set up RF oscillations in the cavities by
a. entering all cavities in equal amounts and at equal speeds
b. entering alternate cavities at different speeds
c. oscillating in all cavities equally
d. grazing the cavity openings and returning to the cathode

The consumption of power due to the transit time of a tube, which occupies an appreciable portion of the input signal, is effectively the same as adding
a. a resistance between grid and cathode
b. a resistance between plate and cathode
c. a resistance between plate and grid
d. none of the above

The method by which the magnetron sustains its oscillations is the
a. electrons giving up energy to the d-c field
b. electrons giving up energy to the RF field
c. electrons giving up energy to the magnetic field
d. stopping of the electrons by the tube's plate

The purpose of using balanced mixers in a radar receiver (fig. 8-44) is to
a. balance out the frequency variations of the received signal
b. balance out noise caused by the local oscillator
c. average the frequency variations of the received signal
d. prevent noise generation by the local oscillator

8. Crystal current is adjusted to its optimum value by
a. a resistive disk-type attenuator
b. local-oscillator tuning
c. local-oscillator coupling
d. a lossy cable

9. In the lighthouse oscillator, the oscillator frequency is
a. above the resonant frequency of the plate tank
b. below the resonant frequency of the cathode tank
c. same as the resonant frequency of the plate tank
d. below the resonant frequency of the plate tank

10. The most common type of magnetron used today is the
a. traveling-wave or resonant cavity type
b. split-anode electron resonance type
c. split-anode negative resistance type
d. double split-anode type

11. In the π mode of operation, a magnetron is operating at
a. greatest efficiency and power output
b. greatest efficiency, but low power output
c. greatest power output, but low efficiency
d. low efficiency and power output

12. Klystrons can be tuned
a. electronically with the buncher grids
b. electronically with the repeller voltage
c. changing the distance from plate to cathode
d. only at the factory

13. The grid and plate tanks of the tuned-grid tuned-cathode oscillator are tuned
a. above the oscillator frequency
b. below the oscillator frequency
c. to the oscillator frequency
d. to resonance

14. The lead inductance which produces degeneration at VHF and UHF operation is
a. plate-lead inductance
b. grid-lead inductance
c. cathode-lead inductance
d. all of the above

15. The cavities of a traveling-wave type of magnetron are connected so that they appear to the output as
a. series connected
b. series, parallel connected
c. separate outputs
d. parallel connected

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16. Straps are used in a magnetron to
    - a. remove power from the cavities
    - b. increase frequency stability
    - c. decrease the coupling between cavities
    - d. excite additional modes of operation

17. The local oscillator in a radar receiver is caused to vary in frequency because
    - a. the magnetron varies in frequency
    - b. frequency modulation is necessary for reception of the reflected signal
    - c. the intermediate frequency must be caused to sweep a relatively wide band
    - d. the magnetron must be caused to vary in frequency

18. A klystron has
    - a. one mode of operation
    - b. two possible modes of operation
    - c. three or more modes of operation
    - d. only one mode of operation for each frequency

19. When the cavity grids of a klystron are adjusted to be closer together, the
    - a. cavity size is made smaller and frequency increases
    - b. cavity size is made smaller and frequency decreases
    - c. capacity between the grids increases and frequency increases
    - d. capacity between the grids decreases and frequency decreases

20. The RF equivalent of the ultraudion oscillator is that of a/an
    - a. Hartley oscillator
    - b. Armstrong oscillator
    - c. Colpitts oscillator
    - d. Butler oscillator

21. One of the functions of a radar modulator is that it
    - a. selects the timing sequence of the radar
    - b. contains all the timing circuits of the radar
    - c. determines the waveform of the output pulse of the magnetron
    - d. supplies normally a positive pulse to the magnetron

22. For best operation of balanced mixers
    - a. both crystals should be matched
    - b. it makes no difference as to the match
    - c. both crystal currents should be equal
    - d. both crystals should have the same RF impedance

23. To increase feedback in the tuned-grid tuned-cathode oscillator you would tune the cathode tank
    - a. more capacitive
    - b. less capacitive
    - c. inductive
    - d. resistive

CHAPTER 9

UHF AND MICROWAVE ANTENNAS

The frequencies which are included in the UHF and microwave ranges extend from 225 megacycles to approximately 30,000 megacycles. These frequencies are divided into bands and are identified by the letters P, L, S, X, and K. The following table shows the approximate frequency range for each band and its letter designator:

P—225 to 390 mc.
L—390 to 1,650 mc.
S—1,650 to 5,200 mc.
X—5,200 to 10,900 mc.
K—10,900 to 33,000 mc.

The UHF range is included in the frequencies of the L and P bands; and the microvave range is included in the S, X, and K bands. The S and X bands are frequently referred to by vavelength instead of frequency. Since the S oand is centered around the wavelength of 10 em., it is referred to as the 10-cm. band, likevise the X band is referred to as the 3-cm. oand. It is important to distinguish between JHF and microwave equipments since they ossess many characteristics that differ beause of their frequency of operation.

The fundamental principles of antennas for se at UHF and microwave ranges are the same s those for use at lower frequencies. These rinciples have been covered in the Navy Trainig Course, *Basic Electronics*, NavPers 10087, nd will not be included in this chapter. It is dvisable that you become thoroughly familiar ith the material in the basic course, for withit such information you will most probably exerience a great deal of difficulty in understandg this chapter.

The major purpose of a transmitting antenna to convert the transmitter's RF power into diated energy as efficiently as possible, and the ajor purpose of a receiving antenna is to absorb much of this radiated energy as possible. order to increase the effectiveness of the anna system, several elements are often combined to form an ARRAY. The antenna array used will be determined by the requirements of the equipment and the particular purpose of the transmission. UHF directive arrays containing several parasitic elements may be built into a very small space. Likewise, directive arrays with parabolic and horn-type reflectors which would be too bulky for use at the lower frequencies become very practical at microwavelengths because of their small physical size.

Some of the antennas described in this chapter are no longer used on naval aircraft. However, their theory of operation is still sound, and most of the terms peculiar to antenna theory still apply. The theory of the older antennas is excellent background leading to the theory of present-day types, and is included for this purpose. Also, much of this theory applies to antennas used with television.

Antenna Arrays

DRIVEN ARRAYS

The driven array consists of two or more elements with all elements connected to the generator. They may be divided into three basic types—the broadside array, the end-fire array, and the collinear array.

Broadside Array

When two half-wave elements are placed one-half wave apart, parallel to each other and excited in phase, most of the radiation takes place in a direction perpendicular to a plane through the elements. The arrangement and radiation pattern of a broadside array are shown in figure 9-1. In it, the radiation pattern is shown in solid lines. Increasing the number of elements makes the pattern more directional.

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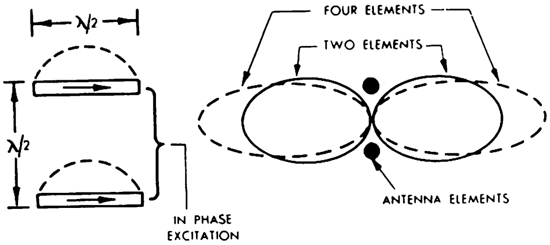

Figure 9-1. —Broadside array.

This increased directivity is shown by the dotted lines.

End-Fire Array

When two elements are spaced a certain fraction of a wavelength apart and are excited out of phase by the same fraction of a cycle, the radiation is directional in the plane of the array and perpendicular to the elements. It is directional from the end of the array that has the most lagging current. If the spacing in an end-fire array, for example, is a half wavelength, the two elements are excited a half cycle or 180 degrees out of phase. This causes the bidirectional pattern shown in figure 9-2. A unidirectional cardioid pattern can be obtained with a quarter wavelength spacing and a quarter cycle (90 degrees) phase difference in excitation.

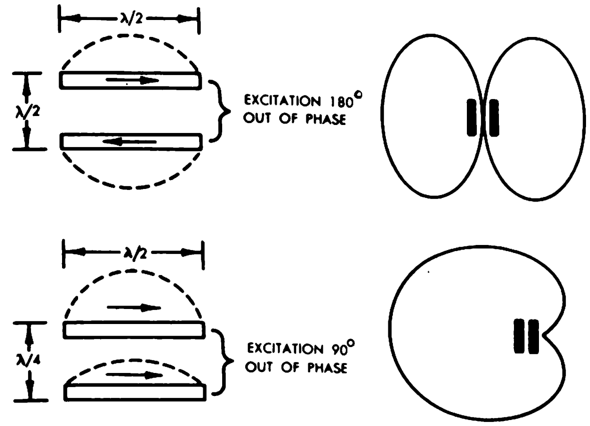

Figure 9-2. —End-fire array.

Collinear Array

A collinear array is formed when two half-wave elements are placed end to end and excited in phase. In a collinear array there is no directivity in the plane perpendicular to the antenna, but there is a sharp pattern in any plane containing the antenna. As with any of the other arrays, increasing the number of half-wave elements increases the directivity of the pattern. This array is shown in figure 9-3.

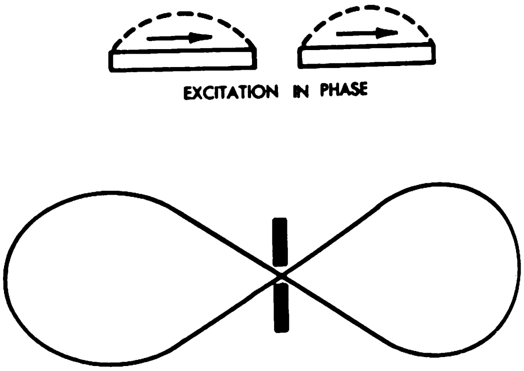

Figure 9-3. —Collinear array.

Parasitic Arrays

A parasitic array is an antenna system which consists of two or more elements in which only one of the elements is driven. The other element (or elements) is excited by induction and radiation fields which are produced by the driven element. With parasitic arrays it is possible to obtain highly directional patterns. The action in a parasitic array is analogous to the action in a transformer in which the primary induces a current in the secondary and the current in the secondary produces a magnetic field, which, in turn, induces current back into the primary. The phase relationship between elements in an array varies according to the spacing between elements. The elements are usually spaced an appreciable part of a wavelength apart.

In a two-element parasitic array, shown in (A) of figure 9-4, the driven element (labeled A) is cut at the center for connecting a low impedance feed line. The length of the driven element is a half wavelength. This makes it self resonant. The parasitic element called the reflector is located 15 percent of a wavelength in space from the driven element. It is about 5 percent longer than the driven element.

Another diagram, (A) of the figure, shows the phase relationships in the parasitic array vectorially. Vector i_d, which represents the current in the driven element, is in phase with the H-field. The part of the H-field that cuts the parasitic element lags the field which leaves the driven element by 0.15 of a cycle. (This is the time lapse during the travel between elements.) The lag is equivalent to 54 degrees. The flux at the reflector is shown by vector Φ. It lags i_d by 54 degrees. The voltage induced by the field is 90 degrees out of phase with the field. This voltage is represented by the vector E_p. If the parasitic element were resonant, the current in it would be in phase with E_p, but the reflector is longer than the resonant half wavelength. A long antenna is inductive and the current in this element will lag the voltage by 36 degrees if it is approximately 5 percent longer. The radiated field will be in phase with this current. In summary, the field starting out from the parasitic element will be 180 degrees out of phase with the field leaving the driven element.

If the polar diagram for two elements spaced 0.15 wavelength apart and excited out of phase s plotted, the curve shown in (A) results. This shows that most of the radiation is on the side of the driven element which is away from the parasitic element, while very little occurs on the ide of the reflector.

Another point is that the field passing from he reflector cuts the antenna (driven element) nd induces a voltage in it. This voltage hanges the input current. The input impedance, which is a function of this current, is about 50 hms as compared to 73 ohms for the antenna lone.

A parasitic element becomes a director when is made shorter than the antenna element. In director most of the energy is sent in a direc-on from the antenna element to the parasitic ement. To see what takes place note the diation pattern and the arrangement of the ray in the diagram in (B) of figure 9-4. The rector is usually about 5 percent shorter and bout 0.1 wavelength from the antenna. Some-mes the impedance is reduced to 20 ohms at e driven element in this array.

Several parasitic elements can be used in njunction with a driven antenna to increase rther the directivity and power gain. The eoretical power gain of directional antenna rays composed of an excited element and vari- s numbers of parasitic elements is as fol- vs:

NUMBER OF ELEMENTS	POWER GAIN
2	2.5 (4.0 db)
3	3.6 (5.6 db)
4	5.0 (7.0 db)
5	6.4 (8.1 db)

Notice the element array called a Yagi antenna in (C) of figure 9-4. In it the antenna or driven element is insulated, but the reflector and all directors are welded to a piece of tubing which runs parallel to the direction of propagation. The beam width of this array is about 19 degrees. The four-element Yagi shown in (D) is constructed similarly to the one in (C) and has a beam width of about 50 degrees.

The conventional method for describing the directivity of an antenna array is in terms either of the ratio of the power in the best lobe to the power radiated by a simple half-wave antenna (antenna gain), or the ratio of the power in

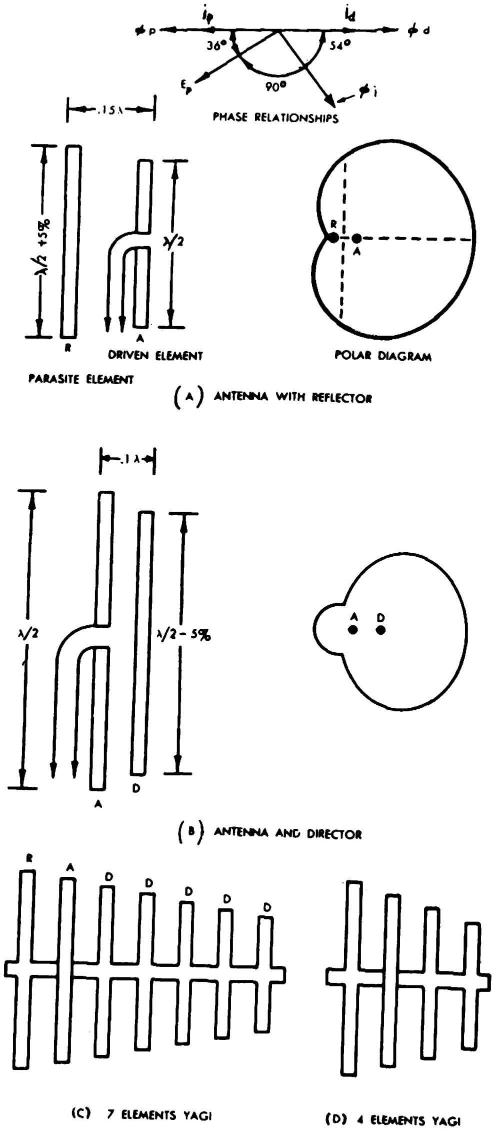

Figure 9-4. —Parasitic array.

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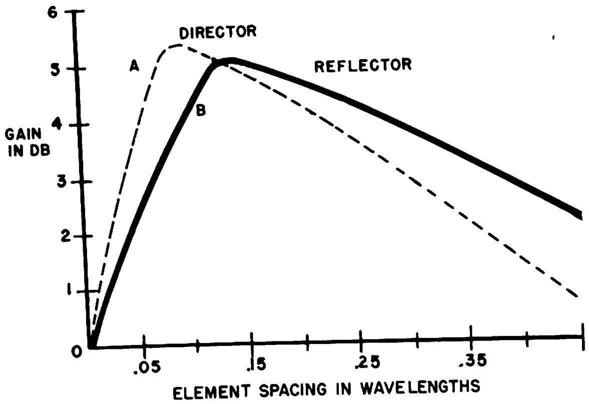


Figure 9-5. —Relative power gains of parasitic arrays for different reflector and director spacings.

the direction of the best lobe to the power in the opposite direction (front-to-back ratio). The direction of the best lobe is usually called FORWARD direction, while that in the opposite is called the BACKWARD direction. In other words, this ratio is the power in the forward field to the power in the backward field. For example, the front-to-back ratio of the antenna array illustrated in (B) of figure 9-4 is about 5:1. In decibels, this represents approximately a 7-db gain. The ratio between forward power and power from a single half-wave antenna is about 4 db.

Figure 9-5 shows the effect of the element spacing on the power gain of an array as compared to the field strength of a half-wave antenna alone. Curve A shows the power gain for director spacings in wavelengths between a half-wave director and the driven half-wave radiator. Curve B shows the power gain for half-wave reflector spacings between the reflector and the driven half-wave radiator.

The graph shows that when a single parasitic element is used, there is little difference in the gain of the array if the parasitic element employed is used either as a reflector or as a director. When the parasitic element is tuned to work as a reflector, the spacing which gives maximum gain is about 0.15 wavelength and this maximum gain peak is fairly broad. The director will give slightly more gain than the reflector, but the difference between the two is less than 0.5 db. Consequently, on the basis of gain, there is little choice between the two types of operation. The broader curve of the reflector does offer a distinct advantage in that the spacing is less critical. Similarly, a small error in reflector spacing will reduce the gain of the array less than a same spacing error in a director type array. For this reason, when a single element is used, the array is usually a reflector type array.

Comparisons between the more directive types of arrays are made in terms of the beam angle. This angle is the angle between half-power points in the main lobe (radiation curve). In arrays the half-power points are the points where the electric field strength (volts per meter) is 0.707 as great as that along the axis of the beam. Figure 9-6 shows the beam angle for a radiation pattern. In this illustration the angle between points A and B, or the angle θ, is the beam angle. At each of these points the signal strength is 0.707 of its value at point C. At A and B the power radiated is one-half the value as at C, thus these points are also known as half-power points.

In multielement arrays the input impedance drops as low as 15 ohms. In these arrays special matching devices are needed for matching this low impedance to the higher impedance of most RF lines. One method for making the match is to use the Delta matching system in which the end of the transmission line that is to be connected to the antenna is spread apart (fanned out) before being connected. The section of the line that is spread apart has a continuously increasing characteristic impedance. The impedance of a half-wave radiator increases

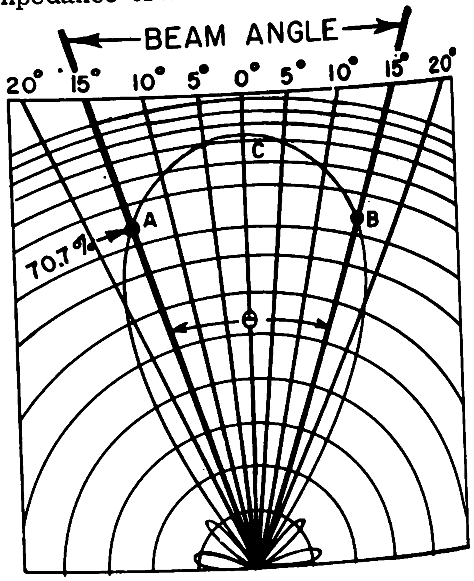
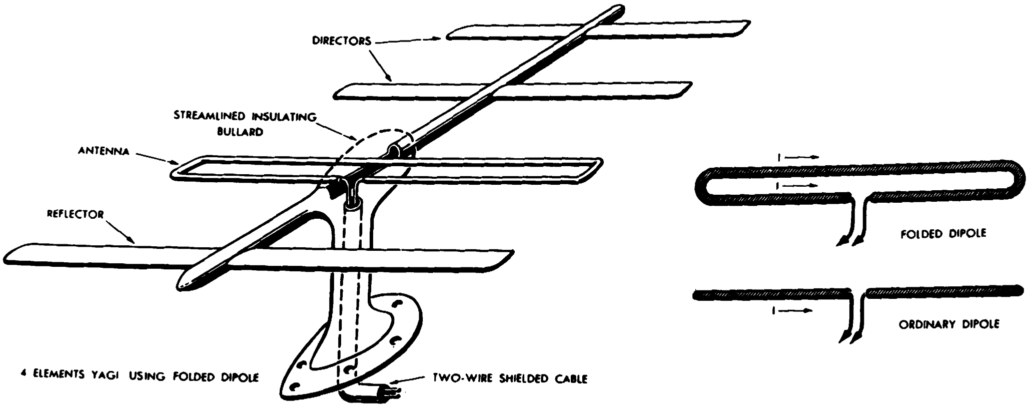


Figure 9-6. —Beam angle and half-power points.



Folded Dipole

Figure 9-7.—Folded dipole.

from 73 ohms in the center to about 2,500 ohms at the ends. Thus, the impedance at any point is determined by the distance from the center. Two points can be found on the radiator where the impedance equals that of the fanned section of the transmission line. The connections are made at these points. Another method, the one most often employed, uses the folded dipole as shown in figure 9-7.

A folded dipole is a full wavelength conductor which is folded to form a half-wave element. A better description is that it consists of a pair of half-wave elements connected together at the nds. In it the voltage at the ends of each element must be the same. In operation, the field rom the driven element induces a current in the econd element. This current is the SAME as the urrent in the driven element.

An ordinary dipole with a given current, I, roduces a certain field intensity in space. Due o this field, there is also a certain power denty per square meter in space. This power ensity is produced by the input power, P. The elationship between the input resistance, the urrent, and the input power is expressed by the quation,

$$R = \frac{P}{I^2}$$

With the folded dipole, the same current, I, ists at the input terminals; but this same curnt flows in both sections of the antenna, and nsequently, the field strength in space is ubled. This causes the power density per uare meter to increase to four times the previous value when the CURRENT AT THE INPUT REMAINS UNCHANGED. In turn the input power must be four times as great. In this case, to balance the equation, it is necessary to multiply R by 4 as follows:

$$\frac{4P}{I^2} = 4R$$

So long as each section of a dipole has the same diameter, the input resistance is four times that of the simple half-wave dipole. Increasing the diameter of one section makes the increase in impedance still greater. The input impedance to the driven element of a parasitic array drops to about a fourth of the value of the coaxial cable impedance, but the use of a folded dipole increases the impedance by about four times. In this way a good impedance match is effected.

INTERCONNECTION OF ELEMENTS IN ARRAYS

There are a variety of ways to connect the elements in an antenna array to obtain the required phase of excitation. The most convenient method to change the phase from one element to another element when they are a half wave apart is with an RF line. In the broadside array shown in (A) of figure 9-8, one element is excited directly from the transmitter. This element is connected to the other element by a half wavelength of RF line. The phase of the voltage along the RF line is shifted 180 degrees per each half wavelength. The leads to the second driven element are reversed. This causes a

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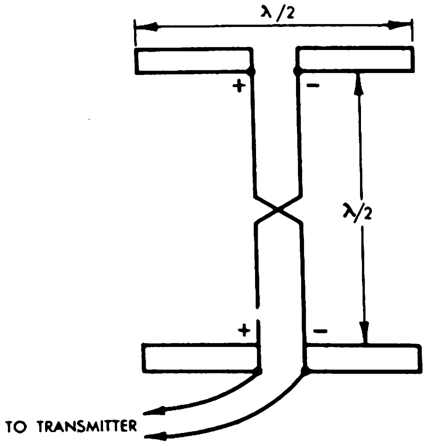
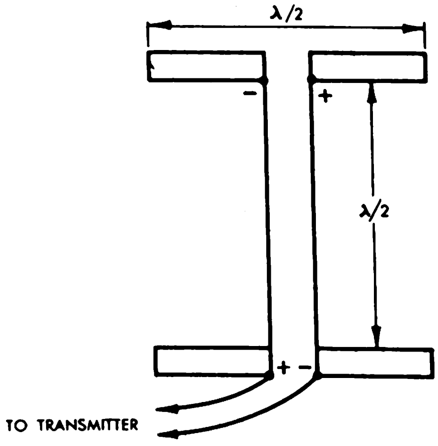
reversal of polarity similar to that resulting from another 180-degree phase shift. The second element is then excited in the same phase as the first.

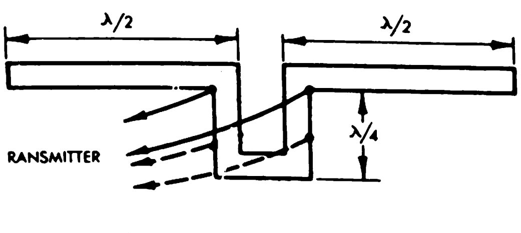
It is possible to connect any number of elements in this manner. In addition, increasing the number of elements makes the array more directional.



(A) BROADSIDE ARRAY



(B) END FIRE ARRAY



(C) COLLINEAR ARRAY

Figure 9-8.—Connecting half-wave elements to obtain proper phase relationship.

In the end-fire array in (B) of figure 9-8, the elements are also interconnected with RF lines. But instead of reversing the leads to the elements, they are connected directly to take advantage of the phase shift. With half-wave spacing, the interconnecting line will be a half wave long and provide a 180-degree phase shift. If quarter-wave spacing is used, the interconnecting line will be a quarter wave long. This arrangement produces a 90-degree shift.

The usual method for providing the correct phase in a collinear array is shown in (C) of figure 9-8. Since the current direction changes for each half wavelength of an antenna, it is not possible to connect the half-wave sections together directly. Instead, the half-wave section which carries the current in the wrong direction is folded to form a quarter-wave section of RF line. This brings together the ends of the sections in which current flows in the same direction. In other words, in terms of voltage it is necessary that the two antenna sections have voltages which are opposite polarity at the open end. Further, note how the line to the transmitter is connected in (C). The connection is made at a point of very high impedance. This requires the use of a resonant line. If, however, a nonresonant line is to be used, it must be connected as shown by the dotted lines. In the diagram the connections near the closed end of the quarter-wave section is a point of low impedance.

THE PARABOLIC REFLECTOR

When a multielement broadside array is excited, the E-field which exists in front of the antenna will be in a single plane, as shown in (A) of figure 9-9, rather than in an arc as is the case in a single half-wave element. The larger the dimensions of this plane in terms of wavelengths, the greater is the directivity of the antenna system, and the narrower the radiated beam.

Although a multielement broadside array gives good results, it is quite complicated in structure. In it every element must be driven and all spacings and dimensions must be quite exact. A much simpler device for producing an electric field in a single plane is the parabolic reflector. As shown in (B) of figure 9-9, the parabola has its focal point at F. If a single antenna is placed at F and caused to radiate a field, the electric field will leave the antenna in all directions at the same rate in the form of an arc as indicated at point A. As each part

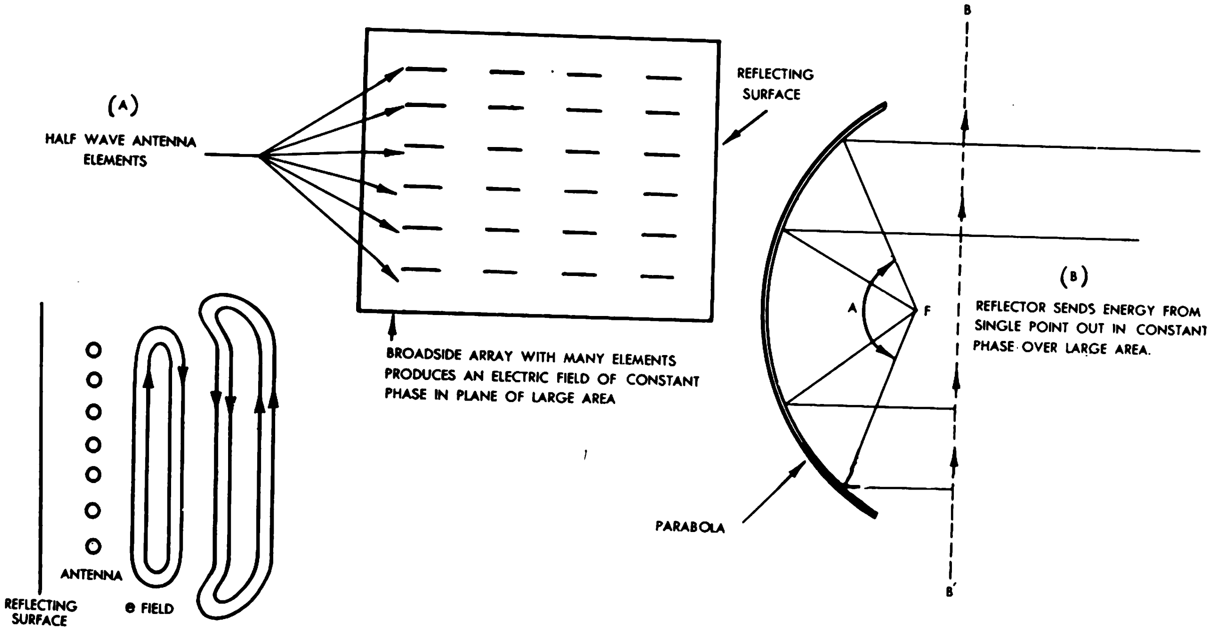

(A)
HALF WAVE ANTENNA ELEMENTS
REFLECTING SURFACE
BROADSIDE ARRAY WITH MANY ELEMENTS PRODUCES AN ELECTRIC FIELD OF CONSTANT PHASE IN PLANE OF LARGE AREA
ANTENNA
REFLECTING SURFACE
e FIELD
B
A
F
(B)
REFLECTOR SENDS ENERGY FROM SINGLE POINT OUT IN CONSTANT PHASE OVER LARGE AREA.
PARABOLA
B'

Figure 9-9. —Directional radiation by means of reflectors.

the wavefront reaches the reflecting surface, is shifted 180 degrees in phase and sent tward at an angle of reflection that is equal the angle of incidence. All parts of the field ll arrive at line BB' at the same time after 'lection because all paths from F, to the 'lector, to line BB' are equal in length. Thus, ı see that with only one antenna and a ecially shaped reflector, it is possible to oduce a large electric field in a single plane. , looking at it another way, all parts of the ld travel in parallel paths after reflection from parabola in such a way that the rays are used like the headlight beam from an autobile.

Like the broadside array, high directivity is obtained until the diameter of the parabolic lector is made many wavelengths long. This hibits the use of the parabolic reflector at frequencies, but for three-centimeter and -centimeter radar equipment these reflectors very practical.

In figure 9-10, showing the exciting antenna a parabolic reflector, the half-wave dipole is nted a quarter wave back from the short on coaxial line. To sharpen the focal point the nna is physically less than a half wave long. ever, the balls at the end make it electrically alf wave long. This broadens the band of frequencies it will handle. The airtight cylinder in which the antenna is enclosed permits the coaxial line to be pressurized. The inner surface of half the cylinder, that is, the side away from the parabolic reflector, is coated with a reflecting foil. This reflecting surface directs energy from that side of the antenna into the large reflector. Without this reflector half of the antenna radiation would be nondirectional.

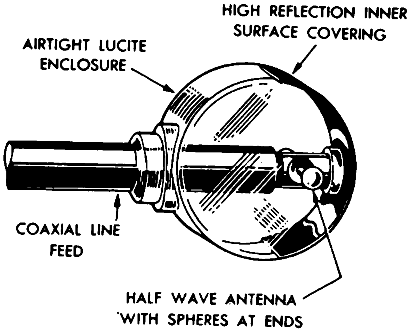

HIGH REFLECTION INNER SURFACE COVERING
AIRTIGHT LUCITE ENCLOSURE
COAXIAL LINE FEED
HALF WAVE ANTENNA WITH SPHERES AT ENDS

Figure 9-10. —Dipole for exciting parabolic reflector in 10-cm. system.

The natural directivity of a dipole causes the pattern from a parabolic reflector to be somewhat sharper in the plane containing the dipole than in the other plane. For this reason, the

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dipole is erected horizontally for maximum azimuth accuracy in radar systems. If vertical accuracy is of primary importance, the dipole is mounted vertically.

Other methods of preventing the direct forward radiation use a parasitic reflector with the half-wave dipole, and a disk which is placed in front of the dipole.

When a waveguide is used in the RF system, it is possible to send the energy into the parabolic reflector with a horn radiator. In this case an orangepeel reflector, or section of a complete circular paraboloid may be used as the reflector. The feed is by a waveguide and a horn-type radiator. The horn-type radiator and orangepeel parabola are constructed in such manner that the radiation pattern of the horn is such that almost all of the energy that it radiates is intercepted and reflected by the reflector. This arrangement is highly directive in the vertical plane and is used principally to determine the altitude of airplanes.

Cosecant-Squared Reflectors

In airborne radar sets that are designed for use in scanning a large area, a special beam shape is required. This is shown in figure 9-11. The beam should be narrow in the horizontal plane but broad in the vertical plane.

In addition, the particular section of the area that is being scanned must not be uniformly illuminated by the radar beam. Instead, the objects near the aircraft should be illuminated by a relatively smaller amount of power than those farther away in the same sector. This is required because echo signals from nearby objects will be strong due to their closeness to the plane. On the other hand, a greater amount of power should fall on more distant objects in this sector since they would normally produce the weakest echoes. Thus, the radiated field produced by the beam should increase in intensity at greater distances. Or, in other words, the field intensity should vary as the cosecant of the angle between the horizontal line of the plane and a line drawn between the aircraft and a given point on the ground. Since power varies as the square of the field intensity, then the required power pattern must be a cosecant-squared pattern.

A common method used to obtain such a pattern is to use a special parabolic reflector in which the top portion is bent forward in order to produce the required pattern. Such a reflector is shown in figure 9-11 along with the radiation pattern produced.

Another type of reflector is shown in figure 9-12. This reflector differs from the one just discussed in that it is capable of producing either a pencil type (narrow beam both vertically and horizontally) or a cosecant-squared pattern. Mounted on the reflector is a rod grating, roughly shaped in the form of a barrel stave, which is polarized and acts as a spoiler to deform the pencil-beam pattern into an equal-energy return (cosecant-squared) pattern. The choice of pattern desired may be obtained by rotating the entire reflector and grating 90 degrees by means of a beam-pattern-change motor and gear train so that, in the position where the spoiler is nonreflective, a pencil-beam pattern is produced,

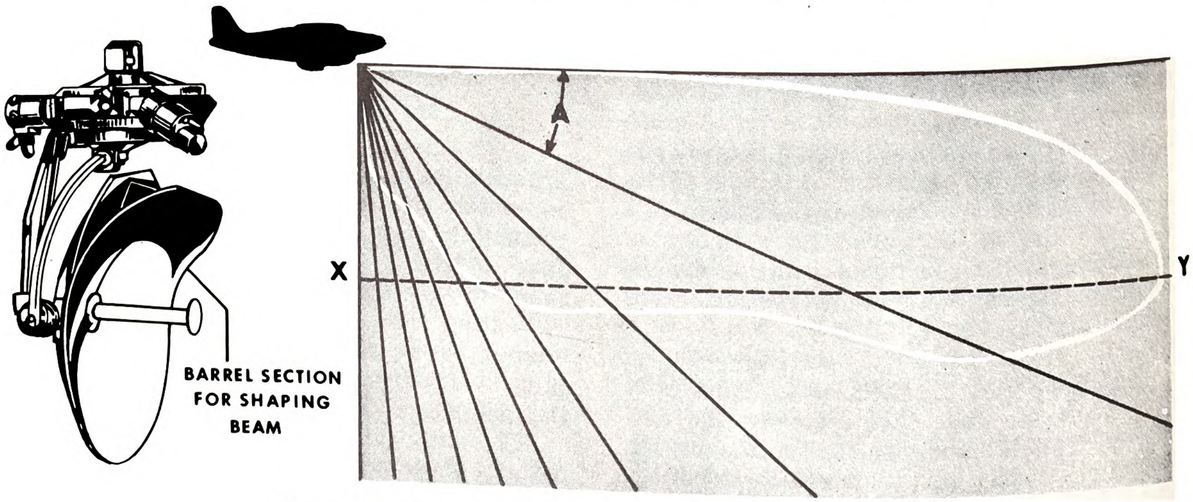

Figure 9-11.—Cosecant-squared antenna and pattern.

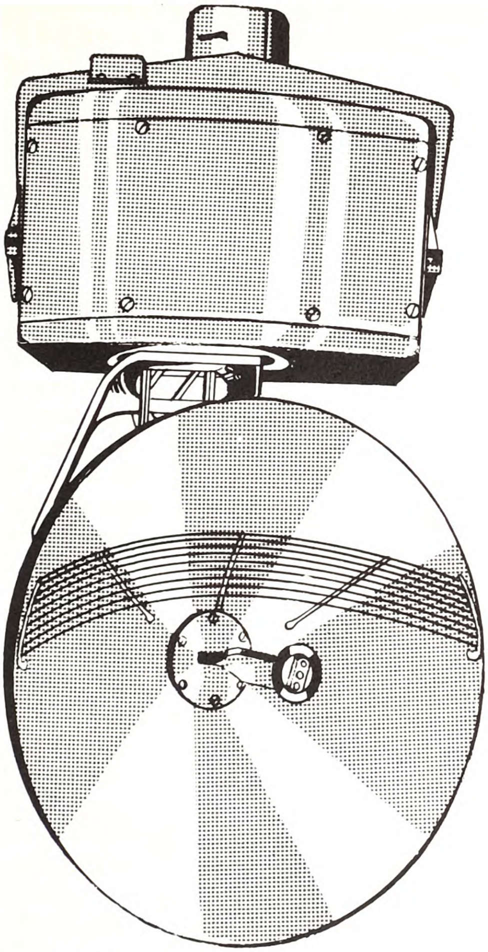

Figure 9-12.—Parobolic antenna with spoiler.

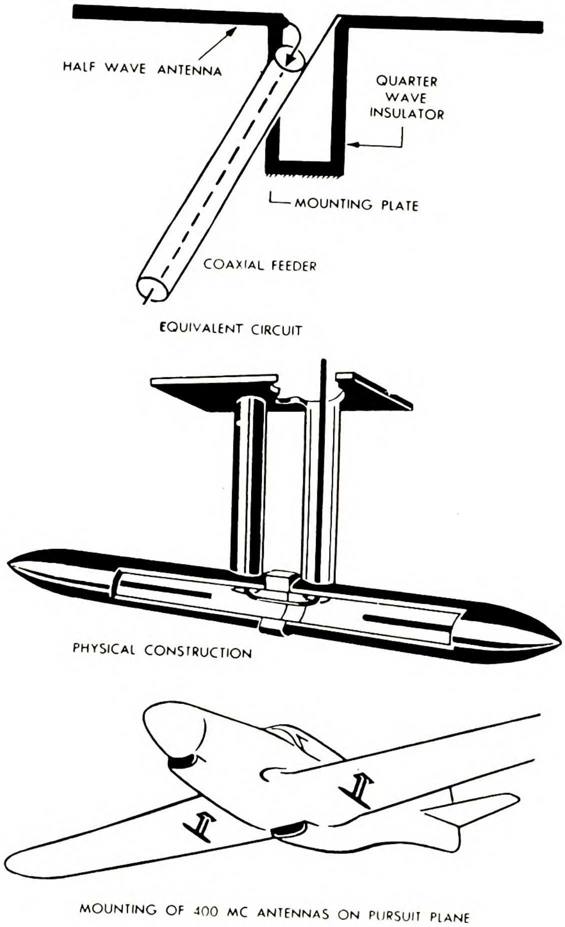

Figure 9-13.—A UHF antenna.

, in the position where the spoiler is re-tive, a narrow, blade-like, equal-energy-rn pattern results.

Some reflectors of this type are equipped a solid spoiler that is hinged to the upper of the paraboloid. The desired pattern may be obtained by causing this spoiler to tilt out of the reflector to a position where the cosecant-squared pattern is produced. In the retracted position the spoiler is flushed with the surface of the paraboloid and a pencil beam is produced.

Typical Airborne Antennas

A UHF BROADBAND ANTENNA

A typical example of a directional UHF an-a system is shown in figure 9-13. This nna has been used with both frequency modu-on and pulsed radar altimeters which re-ed a wide-band characteristic. As you can the antenna is a half-wave dipole con-cted of a large diameter tube which is di-d at the middle and mounted in the slip-am. As it must be able to withstand air pressures at high speeds, it is streamlined by rounding at the ends. It is rigidly mounted on a pair of brass tube supports. Each tube is exactly equal to a quarter wavelength and is welded to a plate that mounts on the aircraft. Together, the tubes form a quarter-wave section which is shorted at the mount end and is open at the antenna end. Each half of the antenna connects to a part of the leg of this quarter-wave section. The entire antenna is perfectly insulated by a quarter-wave metallic insulator.

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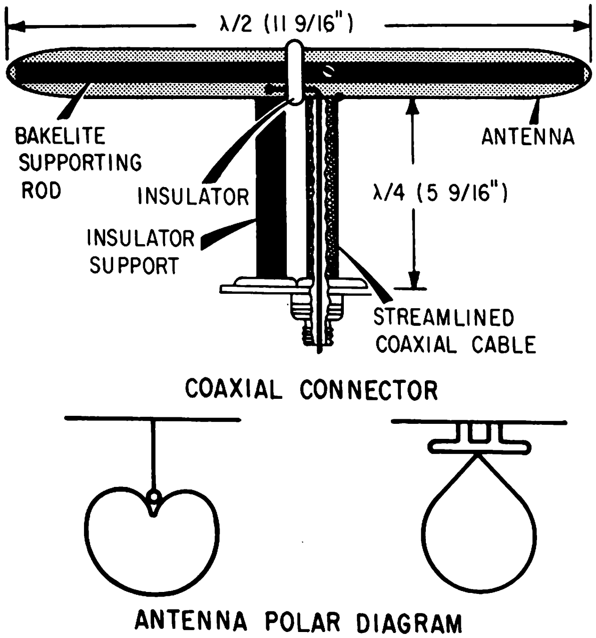

Figure 9-14.—400-mc. antenna dimensions and polar diagrams.

The entire section is connected electrically to the antenna through a coaxial cable. One of the tubes supporting the antenna is the outer conductor for the coaxial cable. A wire through the center of this tube starts from a coaxial connector at the mounting plate and ends at the opposite half of the antenna. Because of the split sections, a bakelite rod inside the antenna tubing is used to give the antenna mechanical strength. The half sections are insulated from one another by a ceramic bushing.

In an installation of this type two antennas are employed—one for transmitting and the other for receiving. Usually each is mounted under a wing. Usually the part of the aircraft which is located between the antennas serves to attenuate any direct signal radiation between them. If this arrangement is not possible, the antennas are mounted end to end along the bottom of the fuselage. Since a half-wave dipole has very little radiation off the ends, the receiving antenna is still isolated from the transmitting antenna. The signal desired is the one that goes from the transmitting antenna to the earth's surface and then returns to the receiving antenna. Each antenna is mounted a quarter wavelength from the metal skin of the airplane. The image antenna in the skin is a half wave from the real antenna and parasitically excited out of phase. This produces a virtual two-element end-fire array. Since no radiation fields go through the skin, all radiation is directed downward in a somewhat narrow lobe, as you can see in the side and front view of the radiation pattern shown in figure 9-14. The large diameter of the antenna itself makes it broadly resonant and causes its characteristics to be fairly uniform over the 40-mc. bandwidth of the equipment.

Another factor that adds to its uniform response over a wide band is its method of support; this support is a shorted quarter-wave section of transmission line. Since the antenna acts the same as an open quarter-wave section of transmission line, as the frequency increases the antenna becomes inductive and the support will be capacitative, thus, tending to keep the antenna resonant. As the frequency decreases the antenna becomes capacitative and the support will be inductive; this also tends to keep the antenna resonant.

SLEEVE ANTENNA

The sleeve or coaxial antenna is a vertical omnidirectional antenna developed to minimize the radiation from the feed line. One type of coaxial radiator is one-half wavelength long. Its top half is a thin whip or rod, and the bottom half is a comparatively large hollow metal tube or cylinder. The coaxial feed line is run up through the sleeve radiator or cylinder, as shown in (A) of figure 9-15. The center conductor of the coaxial line connects to the whip radiator and the outer conductor connects to the sleeve radiator. Since there is no RF field within the sleeve, interaction between the radiator and the coaxial line is minimized.

The section of transmission line within the sleeve acts in conjunction with the sleeve to form a short-circuited concentric line which has an extremely high impedance across the open end. This high-Q parallel-resonant circuit minimizes coupling between the sleeve radiator and the transmission line or hollow supporting mast. Although the sleeve effectively decouples the section of line within it from the sleeve radiator itself as well as from the upper radiator, there will still be some coupling between radiators and the section of the transmission line or mast immediately below the sleeve. This coupling causes some radiation from the vertical portions of the line and/or mast and, as a result, some power is wasted in high-angle radiation. Radiation can be eliminated from the feeder and mast by placing

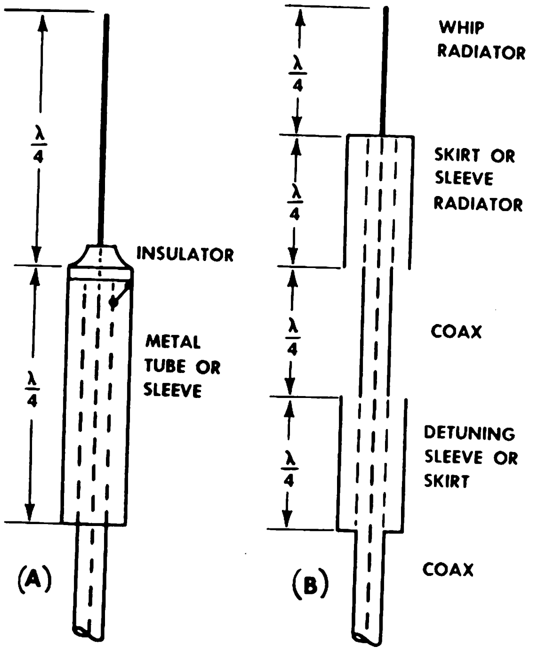

Figure 9-15.—Sleeve antenna.

quarter-wave detuning sleeve below the sleeve diator as shown in (B) of figure 9-15. The tuning sleeve is mounted with its open end cing upward, one-quarter wavelength below e bottom of the sleeve radiator. Its closed d is connected to the mast, or to the outer nductor of the coaxial feed line.

Inasmuch as the coaxial antenna is effectively vertical, center-fed, half-wave radiator, its nter impedance is approximately 70 ohms. A -ohm feed line provides the most efficient tch, but lines up to 120 ohms can be used hout serious mismatch. It is possible to intain a uniform impedance over a larger quency band by increasing the diameter of the ole.

The optimum sleeve length usually runs from 8 to 1.04 of a free-space quarter wavelength. e optimum length for the whip radiator varies m about 0.94 to 0.96 of a quarter wavelength.

GROUND-PLANE ANTENNA

A vertical quarter-wave antenna several elengths above ground produces a high angle radiation which is very undesirable at the high and ultra high frequencies. The most mon means of producing a low angle of ation from such an antenna is to work the radiator against a simulated ground called a GROUND PLANE. A simulated ground may be made from a large metal sheet or several wires or rods radiating from the base of the radiator. An antenna so constructed is known as a GROUND-PLANE ANTENNA.

Several types of ground-plane antennas are shown in figure 9-16. The radius of the ground sheet or the length of the rods used should be one-quarter wavelength or longer. The function of a ground plane corresponds to that of a counterpoise used with low-frequency vertical antennas.

This type antenna is frequently used with VHF and UHF communications equipment in aircraft. The skin of the aircraft serves as the ground plane. When this type antenna is used with a ground installation, it is necessary to employ a ground plane as illustrated in figure 9-16. Without the use of a ground plane it will be impossible to obtain proper loading and efficient radiation.

Since there are no ordinary transmission lines having a characteristic impedance low enough to permit a direct connection to the 20- to 36 ohm impedance of the ground-plane antenna, it is necessary to use a quarter-wave matching section to obtain an acceptable match.

If it is desired to avoid the use of a matching section with its accompanying power losses and bandwidth limitations, the radials can be arranged to slope downward in the manner of an inverted cone as shown in (C) of figure 9-16. The impedance increases as the angle between the radials and the horizontal plane increases. This method can be used to secure a suitable match to a 52-ohm transmission line. The impedance can be increased further to match a 72-ohm line by bending the radials down parallel to the transmission line or supporting shaft as shown in (D).

An ultrahigh frequency, streamlined blade, broadband antenna for general-purpose use over the range of 225 to 400 megacycles per second is shown in figure 9-17. This antenna consists essentially of a near quarter-wave stub, fed through a matching section within the base. It is designed for mounting upon the exterior skin of an airplane. The antenna is streamlined for high speeds. Its cross sections take the form of ellipses on the leading half of the body and of parabolas on the trailing half. The resulting form has a minimum drag effect. The antenna is designed to withstand pressures resulting from airspeeds up to 600 miles per hour.

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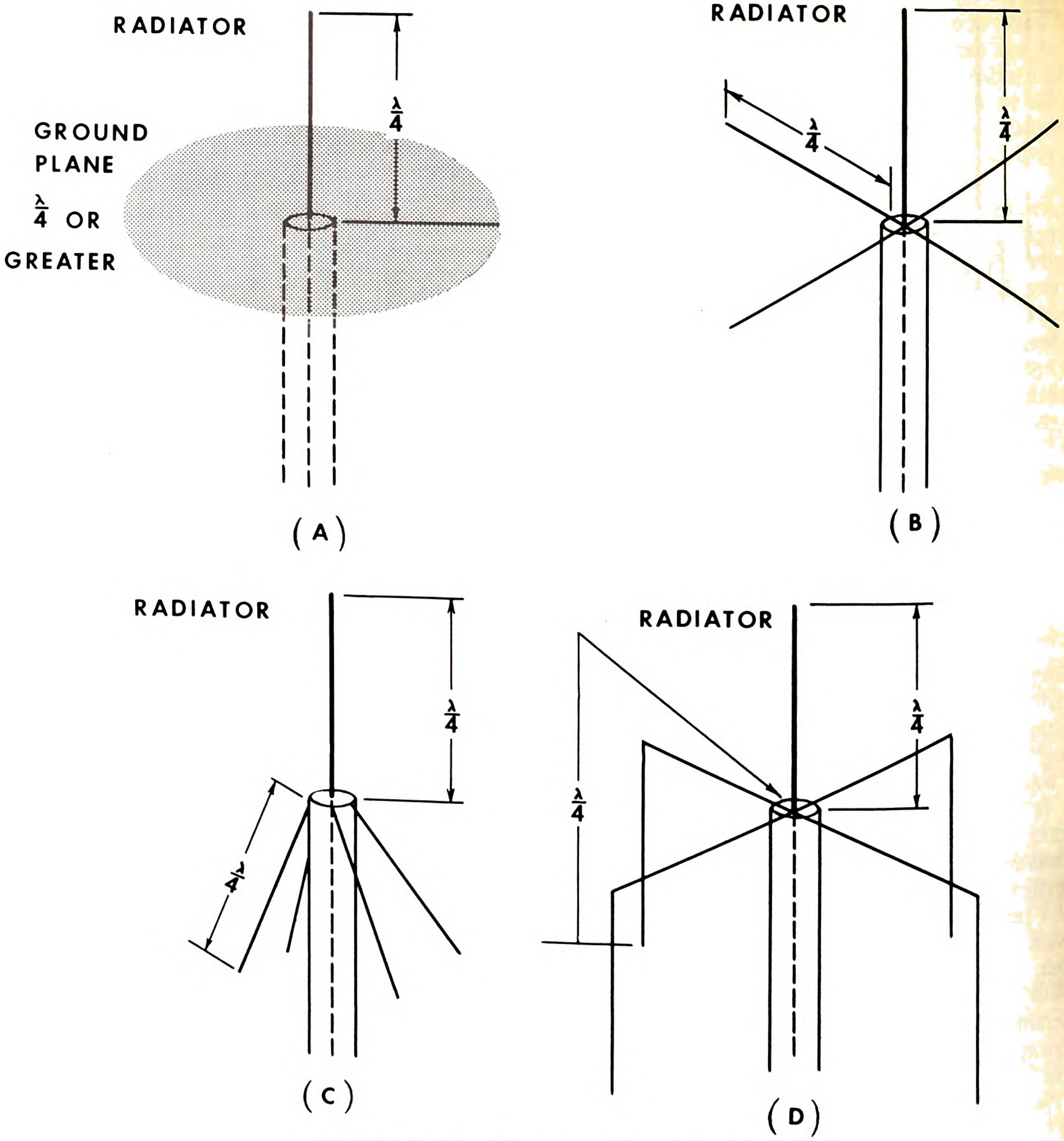


Figure 9-16.—Ground-plane antennas.

The antenna is one self-contained unit, made up of three sections all securely fastened together. The base section and radiating tip are made of aluminum, the central section is a molded resin reinforced with glass fibers. No accessories are required other than those for mounting and connecting. The radiating element is a solid aluminum casting with an inner cone-shaped nipple curving down to the feed point.

A single broadband antenna of this type may be connected to two or more pieces of equipment that operate on different frequencies. The limiting factor is that the equipments must operate within the frequency range of the antenna. When this is done, it is necessary to use band-pass filters in series with the antenna cables. These filters provide the attenuation that is necessary in order to isolate the various

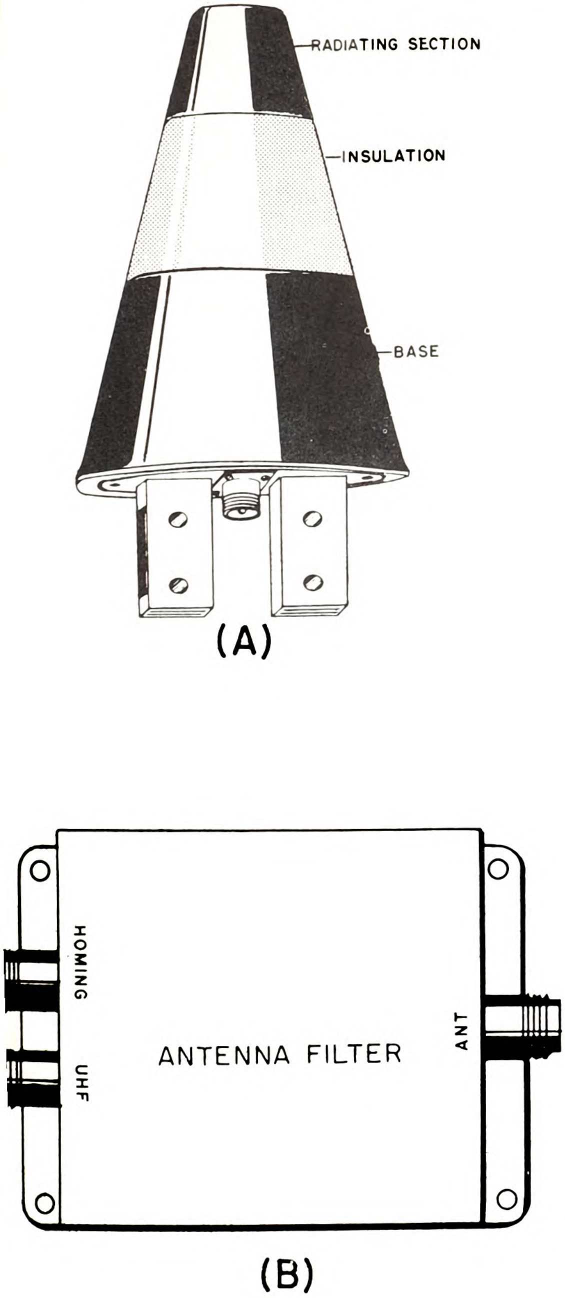


Figure 9-17.—UHF blade antenna.

pments that are connected to the single an-
a. A filter of this type is shown in figure
' (B).

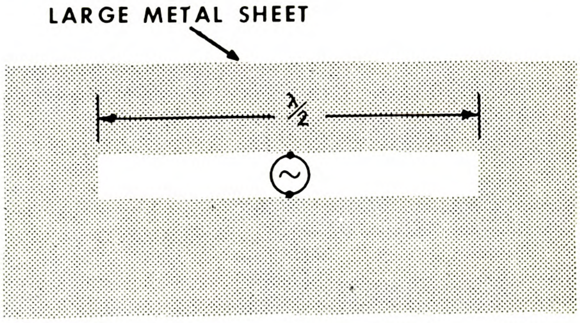
These filters consist of lumped constants,
;, and capacitors and are designed to have
' or less insertion loss in the pass bands.
attenuation in the bands varies from 25 db
ver 80 db depending on the frequency. The power handling capacity of each filter is usually over 700 watts peak power in the pass band, the average power capacity being about 100 watts depending on the frequency.

The antenna shown in (A) of figure 9-17 could be used with a UHF transceiver and a UHF homing receiver at the same time.

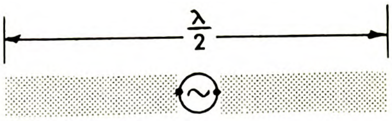
SLOT ANTENNA

The slot antenna consists of a radiator formed by cutting a narrow slot in a large metal surface. Such an antenna is shown in figure 9-18. The slot length is a half wave while the width is a small fraction of a wavelength. Such an antenna is frequently compared to a conventional half-wave dipole consisting of two flat metal strips whose sizes are such that they would just fit into the slot cut out of the large metal sheet. This comparison is made since the radiation pattern produced by the slot antenna when cut into an infinitely large metal sheet and that of the complementary dipole antenna are the same.

It is of interest to note two important differences between the slot antenna and its complementary antenna. First, the electric and magnetic fields are interchanged. In the case



SLOT ANTENNA



COMPLEMENTARY DIPOLE

Figure 9-18.—Slot and complementary dipole antenna.

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of the dipole antenna shown, the electric lines are horizontal while the magnetic lines form loops in the vertical plane. With the slot antenna, the megnetic lines are horizontal and the electric lines are vertical. These electric lines are built up across the narrow dimension of the slot. As a result, the polarization of the radiation produced by a horizontal slot is vertical. If a vertical slot is used, the polarization is horizontal.

A second difference between the slot antenna and its complementary dipole is that the direction of the lines of electric and magnetic force reverse abruptly from one side of the metal sheet to the other. In the case of the dipole, the electric lines have the same general direction while the magnetic lines form continuous closed loops.

When energy is applied to the slot antenna, currents flow in the metal sheet. These currents are not confined to the edges of the slot but rather spread out over the sheet. Radiation then takes place from both sides of the sheet.

A coaxial line is frequently used to feed the slot antenna. The outer conductor of the feed line is bonded to the metal sheet while the inner conductor is connected to the opposite side of the slot as shown in figure 9-19. Note that the coaxial line is not connected at the center of the slot length since a severe impedance mismatch would occur.

The impedance at the center of a slot whose electrical length is a half wave is 530 ohms. This impedance is reduced to a lower value as the input connection is moved toward the end of the slot. At a point about one-twentieth of a wavelength from either end, the input impedance falls to about 50 ohms. A coaxial line may then be connected here without serious mismatch. The slot length may be increased to a full wave if it is desired to connect the coaxial line to the center of the slot. With a full-wave slot, the input impedance at the center of the slot is 50 ohms.

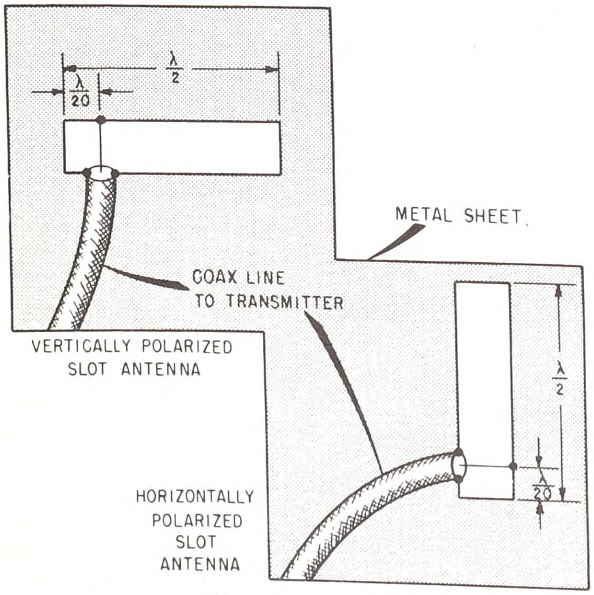

Figure 9-19.—Feeding slot antennas.

Frequently, it is desired to produce radiation from only one side of the metal sheet in which the slot is cut. This is conveniently arranged by boxing in the slot with a section of waveguide. If the depth of the waveguide is a quarter wave (fig. 9-20), then the waveguide will introduce no reactance. Under these conditions, the input impedance at the center of the slot is about 1,000 ohms and the impedance at a point about one-twentieth of a wavelength from either end is about 100 ohms.

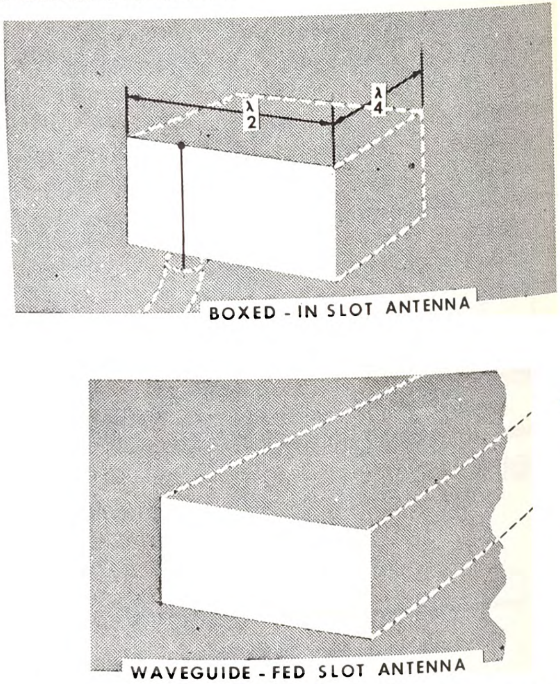

Figure 9-20.—Unidirectional slot antennas.

Another convenient method of making a slot antenna radiate from only one side of the metal sheet in which it is cut is to energize the slot by means of a waveguide as shown in figure 9-20. This does away with the coaxial feeder altogether.

It has been mentioned that the radiation pattern produced by a slot antenna is the same as t produced by a complementary dipole anna. This is true only if an infinitely large tal sheet is used. As the width of the metal et is reduced, the amount of radiation that urs at small angles to the plane of the metal et is reduced considerably. This is shown in re 9-21. The radiation pattern produced by omplementary dipole antenna in the plane pendicular to the antenna is also shown for nparison. In this pattern, you are looking the end of the dipole. If all radiation disappeared to the left of the vertical centerline shown in the illustration, then you would have the radiation pattern produced by a boxed-in slot antenna. (See (A) of fig. 9-21.) Here you are looking along the edge of the metal sheet in which the slot is cut. The length of the slot is at right angles to the plane of the page and the radiation patterns shown are in the plane of the polarization of the energy.

If the width of the metal sheet is a little over 5 wavelengths, then the scalloped pattern

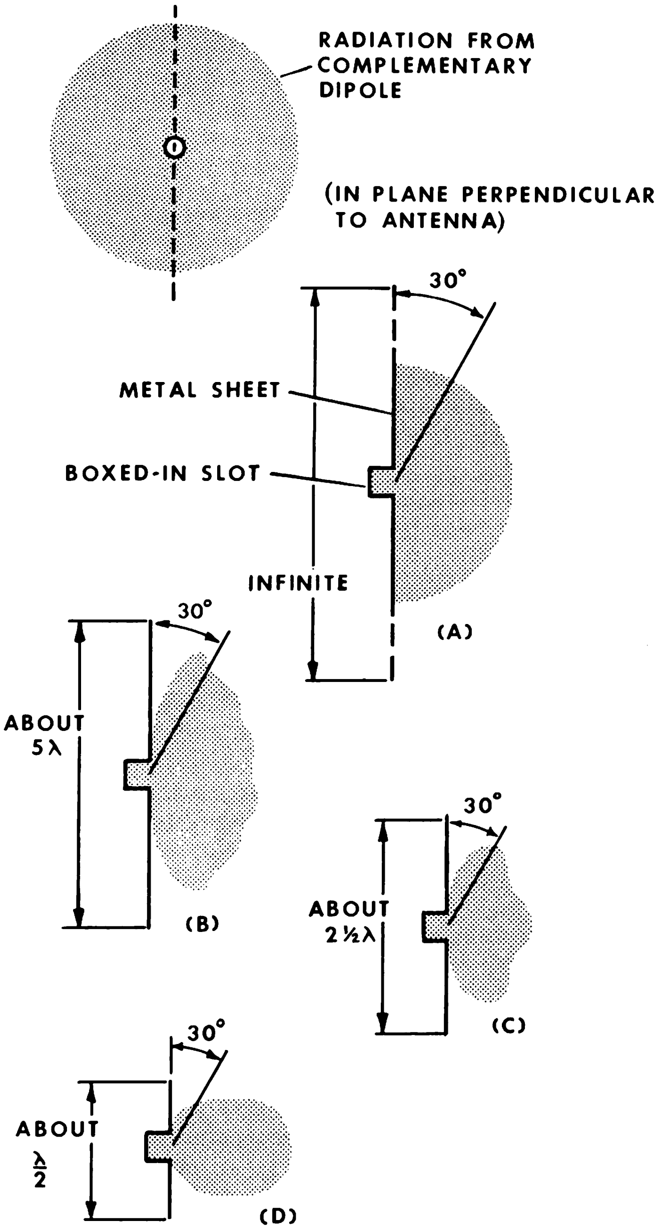

Figure 9-21.—Radiation from boxed-in slot antennas.

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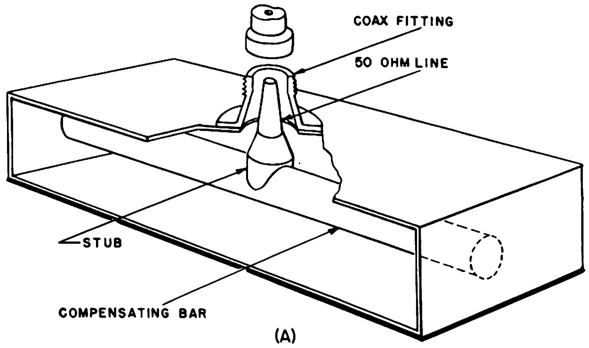
shown in (B) results. As the width of the sheet is further reduced to slightly over 2 1/2 wavelengths, fewer irregularities appear in the pattern, as shown in (C). Also note the reduced radiation at a fixed angle (say 30 degrees) with respect to the metal surface. At a width of only about a half wavelength, the pattern shown in (D) bears only a little resemblance to that shown in (A). The radiation produced at an angle of 30 degrees is further reduced. In practice, since the size of the metal surface in which the slot is cut is usually quite large (compared to a wavelength), radiation patterns having a form somewhere between that shown in (A) and (B) are common.

A type of slot antenna which was developed for use over a very wide frequency band and which could be fed by coaxial line is shown in figure 9-22. With the compensating bar (providing capacitive loading) and stub as shown, this antenna has a standing-wave ratio of less than 2 to 1 over a frequency range from about 30 percent below to about 30 percent above the design center frequency when fed with 50-ohm coaxial cable. Such an antenna may be constructed in a large flat metal surface or it may be made to conform with a curved metal surface. For example, the curved slot antenna shown in (B) can be installed in the leading edge or tip of an aircraft wing. With such a severely curved large metal surface, the radiation pattern produced is quite different from that produced with a slot in a flat surface. The extent of the curvature has considerable effect on the radiation produced.



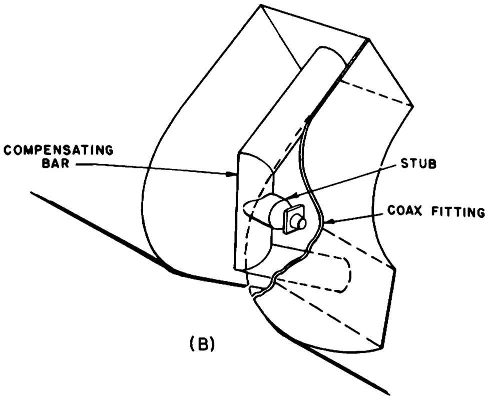


Figure 9-22.—T-fed slot antennas.

Still another form of the slot antenna is shown in figure 9-23. Here the large metal sheet is eliminated completely. Instead, an array of diagonal slots is cut into a length of waveguide. The slots are spaced at intervals along the waveguide so that they are excited in phase. Maximum radiation takes place in the direction indicated.

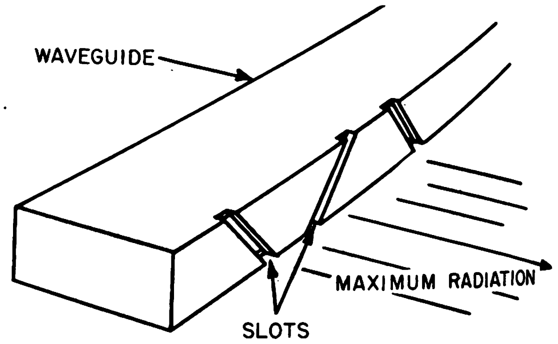
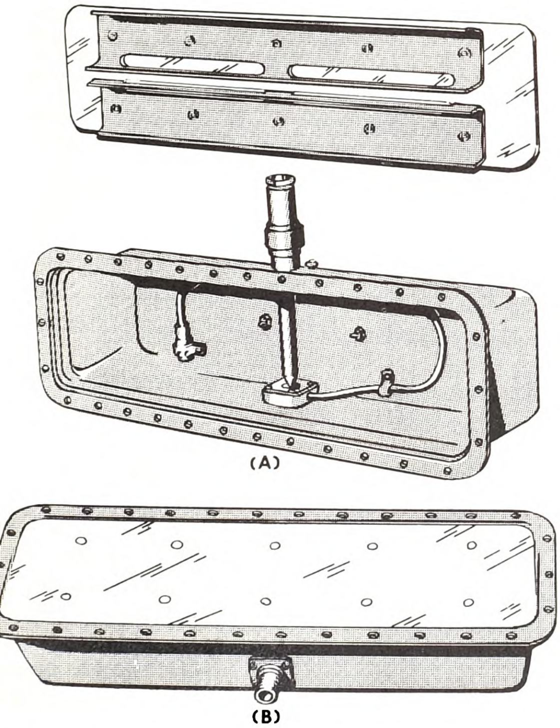


Figure 9-23.—Slot array.

Slot antennas are adaptable for the VHF and UHF ranges. Their most important practical advantage is that the feed section which energizes the slot may be placed below the large metal surface in which the slot is cut. Thus, nothing need protrude from the surface. In addition, the slot itself may be covered by a section of insulating material so that the opening is closed. As a result, no air resistance occurs. This is particularly important in the case of high-speed aircraft where the vibration problems and drag that would be introduced by conventional antennas cannot be tolerated.

When a slot antenna is installed on an aircraft, particular attention should be paid to the slot location with respect to large protuberances. Wings, fuselage, or engine will act to cut off a large portion of the energy radiated from a slot if these objects are located between the slot and the receiving location. Favorite locations for slot antennas on aircraft include the leading edge of the wing and the side of the nose.

The slot antenna illustrated in figure 9-24 is
sed as the radiator with airborne radio altim-
ters. Two such flush-mounted antennas are
sed in the installation, one for transmitting
nd one for receiving. The internal arrangement
ig. 9-24 (A)) of the slot antenna includes the
eed element, a tuning stub, and capacitor plates
ttached to the fiber-glass cover plate) to load
e cavity.



igure 9-24.—Radio altimeter slot antenna.

SKIN ANTENNA is a type of flush-mounted
nna used in aircraft. Such antennas are gen-
ly used in high-speed aircraft where it is
ssary to eliminate the speed-reducing aero-
mic drag produced by the usual types of
na installations. The skin antenna is made
lectrically isolating a portion of the metal
of the aircraft and using this section as the
ting surface of the antenna. In one type of
llation, a plastic section insulates the metal
at the wingtips from the rest of the skin
e aircraft as shown in figure 9-25. The
ip section connects to the receiving and
mitting equipment through an impedance-
hing network and coaxial cable.
ne range of a skin antenna approximates
f fixed-wire antennas for the same fre-
y coverage. Although the illustration in

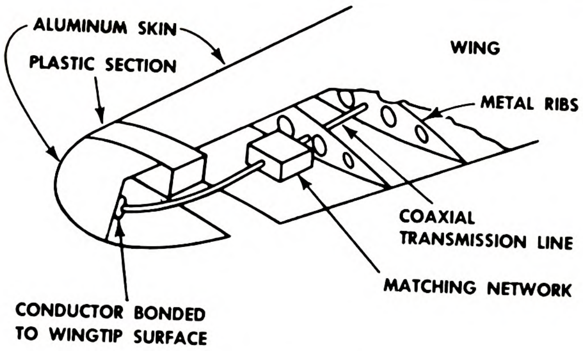

ALUMINUM SKIN
PLASTIC SECTION
WING
METAL RIBS
COAXIAL TRANSMISSION LINE
MATCHING NETWORK
CONDUCTOR BONDED TO WINGTIP SURFACE

Figure 9-25.—Wingtip antenna.

figure 9-25 shows a wingtip installation, skin antennas can also be made a part of suitable tail or fuselage surfaces. The radiation patterns depend on the operating frequency, the size of the radiating surface, and the location of that surface on the aircraft.

Other types of flush-mounted antennas which find wide use in VHF and UHF aircraft communications and radar installations consists of loops, dipoles, and parasitic and driven arrays encased in plastic housings or canopies forming the tip of a wing, elevator, stabilizer, or nose.

CORNER REFLECTOR

When a unidirectional radiation pattern is desired, such a characteristic can be obtained by the use of a corner reflector. A corner-reflector antenna is a half-wave radiator with a reflector consisting of two plane metal surfaces meeting at an angle immediately behind the radiator. In other words, the radiator is set in the plane of a line bisecting the corner angle formed by the reflector sheets. The construction of a corner reflector is shown in figure 9-26. Corner-reflector antennas are mounted with the radiator and the reflector horizontal when horizontal polarization is desired. In such cases, the radiation pattern is very narrow in the vertical plane, with maximum signal being radiated in line with the bisector of the corner angle. The directivity in the horizontal plane is approximately the same as for any half-wave radiator having a single-rod type reflector behind it. If the antenna is mounted with the radiator and corner reflector vertical (as shown), maximum radiation is produced in a very narrow horizontal beam. Radiation in a vertical plane will be the same as for a similar

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radiator with a single-rod type reflector behind it.

At frequencies in the VHF and UHF bands, the corner reflector is often made from solid metal sheets. At lower frequencies, such sheets are massive and are easily damaged by high winds. Therefore, screen wire or metal rods located in the plane of the reflector sheets and running parallel to the radiator are used instead. The spacing between the rods must not be more than 0.06 wavelength at the operating frequency.

The gain and the radiation resistance of a corner-reflector antenna are both affected by the reflector corner angle Φ and the spacing, A, between the radiator and the corner as shown in figure 9-26, as well as the construction of the antenna and reflector. The gain (expressed as a power ratio between the dipole with a reflector and the dipole alone) for several corner-reflector antennas is shown in the graph in figure 9-27. Here the gain is shown for various spacings between the dipole and the corner reflector, and for an angle Φ of 90, 60, and 45 degrees.

Sometimes the corner reflector is used as a PASSIVE RADIATOR. Under these conditions, the reflector is NOT excited by a dipole that is mounted with the reflector. Instead, the reflector is acted on by a distant transmitting antenna. Here, the purpose of the corner reflector is to return the greatest amount of energy possible back in the direction from which it originally came.

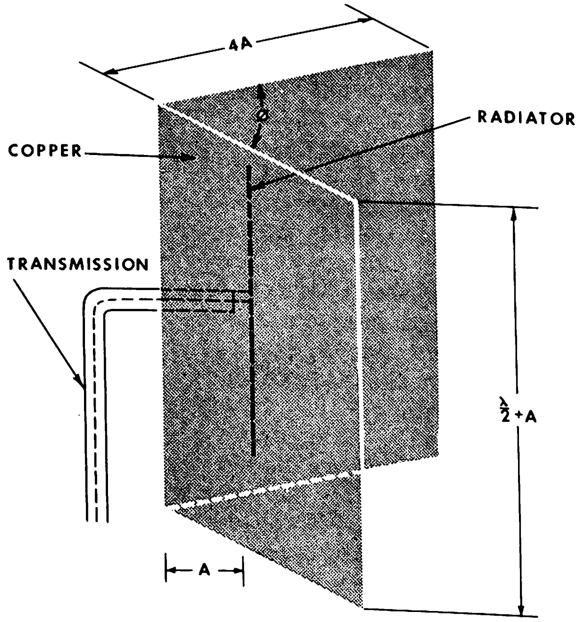

Figure 9-26.—Corner-reflector antenna.

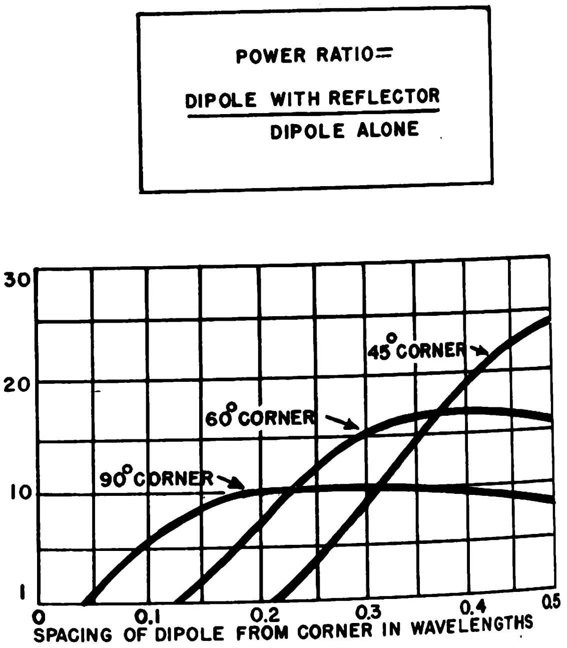

Figure 9-27.—Gain of corner-reflector antenna.

The most important use of the corner reflector as a passive radiator is in radar applications. Here, it is sometimes necessary to make good radar targets from objects which do not ordinarily reflect back enough of the transmitted radar beam to disclose their presence. For example, it is normally very difficult for a searching aircraft to locate by its radar a rubber liferaft, particularly in a rough sea. If a corner reflector is installed on the raft, then it becomes possible for an aircraft radar to detect the raft over a distance of many miles. Corner reflectors are also used to mark the edges of landing fields or a particular runway so as to provide a well-marked point for the aircraft or ground radar equipment. Corner reflectors are frequently installed atop important buoys or strategic points of land which would otherwise not be good radar targets.

The appearance of a corner reflector used for marking radar targets is shown in figure 9-28. Three mutually perpendicular metal surfaces similar to the arrangement of the floor and two side walls at a room corner are used. It should be noted that in the passive corner reflector the corner angle Φ is always 90 degrees. If a radar beam is directed into the reflector, reflections may occur from all

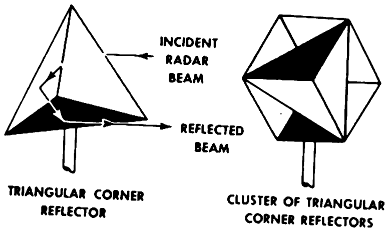
INCIDENT RADAR BEAM
REFLECTED BEAM
TRIANGULAR CORNER REFLECTOR
CLUSTER OF TRIANGULAR CORNER REFLECTORS

Figure 9-28.—Passive corner reflectors.

three surfaces, from two surfaces, or from one surface, depending on the angle of arrival of the beam. In any case, the reflections cause he radar beam to be returned in the direction rom which it came. Under these conditions, the adar antenna picks up the reflected energy and letection occurs.

A single corner is effective only for energy hat arrives from directions covering one octant f a sphere centered at the reflector. If it is esired to have coverage in all directions (such s would be the case for liferaft detection), nen a cluster of eight such corner reflectors s used.

The size of such reflectors is not critical o long as the length of a short side is many avelengths long at the frequency of the de- cting radar. The corner-reflector cluster hich is included as part of the emergency res- ue equipment on liferafts is a collapsible struc- re made of screen and measuring two feet on short side. The reflector is mounted about ur feet above the raft.

CONE ANTENNA

It frequently becomes desirable for a trans- tting or receiving antenna to operate over a de band of frequencies. This is especially e in electronic countermeasures and air- ne communication equipment. In order to rate over a wide band it is necessary that characteristics of the antenna system be h that the radiation pattern is not appreci- y changed over the frequency range involved. s also necessary that the standing wave ratio held to a minimum in order to prevent ex- sive losses.

The impedance of resonant wire antennas will y with frequency, thus they will function quately over only a narrow frequency band. As viously stated, in connection with the sleeve nna, it is possible to maintain a uniform impedance over a wider frequency band by increasing the diameter of the antenna elements. This increase in diameter reduces the Q of the resonant system and this in turn causes a reduction in the reactive energy stored in the E and H fields adjacent to the antenna.

A cone antenna is a good example of increasing the diameter in order to obtain wideband operation. The bandwidth of this type antenna can be further increased by the use of compensating reactances. By the use of these series and shunt reactances, it is possible to increase the operating frequency range of the antenna as much as six times.

Figure 9-29 shows two cone-type high-frequency antennas for use with ECM equipment. The electrical connections are brought to a receptacle at the bottom of the antenna. The antenna flange is designed to be mounted flush with the skin of the aircraft. A plexiglass dome or blister is used to cover the antenna in order to afford protection and to reduce wind resistance. The antenna illustrated in (A) should be mounted vertically to receive vertically polarized waves and horizontally to receive horizontally polarized waves. The antenna in (B) is similarly constructed except that the conical pickup element is mounted at an angle of 45 degrees to the mounting flange. This permits reception of either horizontally or vertically polarized waves for a single mounting position.

Some antennas of this type have a high-pass filter incorporated in their assembly that attenuates all frequencies below their designed operating range. Signals below the operating range are filtered out and do not reach the equipment. It is important when selecting antennas of this type, especially for ECM equipment, that a close check be made since an antenna that is equipped with this type filter will pick up a negligible amount of energy below its operating range.

The location of the antenna will vary depending upon the specific problems of the installation. It is extremely important to know that at all frequencies, especially UHF and microwave, it is possible to reduce the efficiency of an installation through the use of excess antenna cable lengths and connectors. Antenna runs should be kept to a minimum length. In most cases the *Handbook of Service Instructions* will specify maximum lengths. It is also important that either the designated type or a lower loss cable be used in all installation work.

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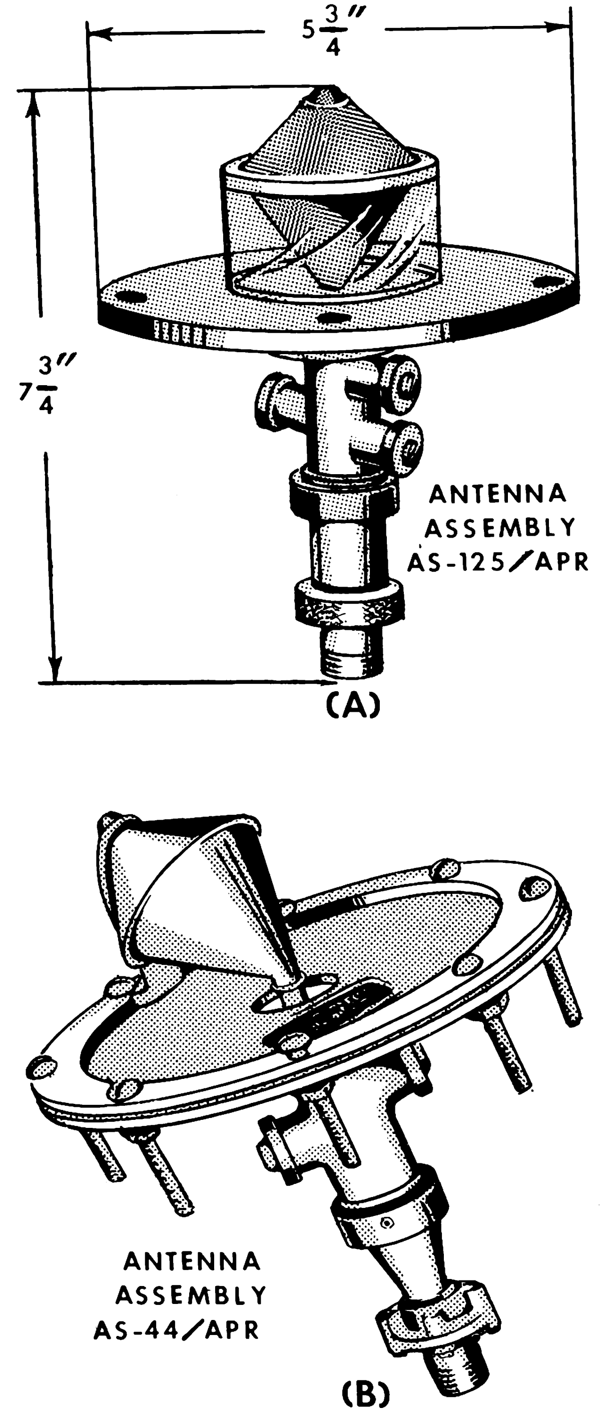

Figure 9-29.—Cone antennas.

A publication, *Index of RF Transmission Lines and Fittings*, NavShip 900-102B, is available upon request. This publication contains charts of attenuation versus frequency for various types of transmission lines, assembly data for connectors, waveguide data, and other information. The charts will be helpful in determining attenuation losses for an antenna cable at a particular frequency. An example of attenuation loss is as follows: RG8/U cable has an attenuation of 9 db per 100 feet at 1,000 megacycles. If a 1,000-watt transmitter is connected to an antenna with 33 1/3 feet of cable, the power at the antenna will be only 500 watts; thus, half the power will be dissipated by the cable. It is also possible to increase the losses of the system by using older type high-loss connectors. Even with the newer type low-loss connectors it is advisable to use as few as possible. This may be partially accomplished by using a minimum of right angle and through-the-bulkhead connectors; also, adapters should be used sparingly.

A modified cone antenna is shown in figure 9-30. This assembly consists of a cylindrical antenna with an inverted cone-shaped base fitted into a mounting flange. It is designed as a jamming transmitter antenna and covers the frequency range of 200 to 550 megacycles.

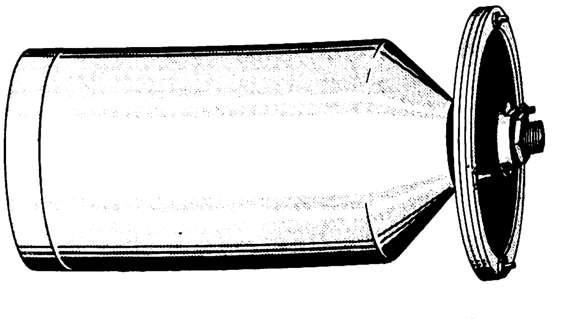

Figure 9-30.—Antenna assembly.

A variation of the cone antenna is illustrated in figure 9-31. It is a flat, diamond-shaped metal plate enclosed in a streamlined plastic housing and is omnidirectional. The actual antenna is shown in (A) of the figure and the equivalent circuit of the antenna system is shown in (B).

An antenna of this type when operated at about 1,000 megacycles will provide efficient operation over a bandwidth of approximately 200 megacycles. Since this antenna is made of a flat piece of metal, it may be mounted in an air foil type plastic housing that offers little wind resistance. This is especially desirable for high-speed aircraft.

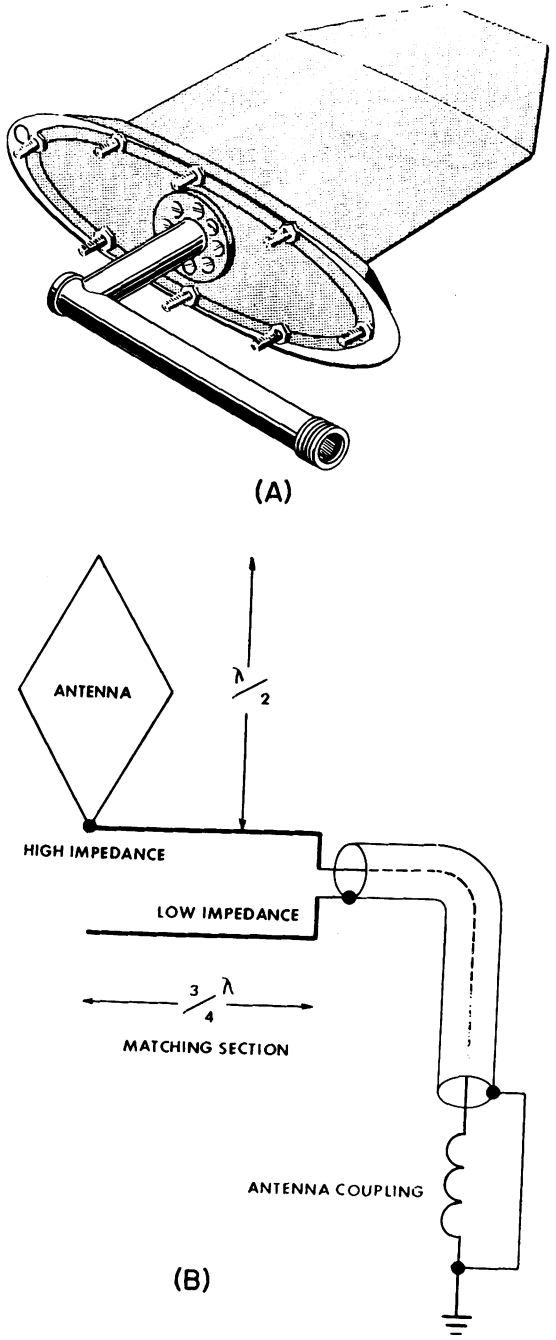

Figure 9-31.—UHF diamond antenna.

e radiator is made diamond shaped, in to obtain broadband frequency character- and is vertically polarized. Since it is d, its impedance is comparatively high ıms) and a matching section of transmis- ne is used to match this impedance to the 51-ohm transmission line. This section, which is a three-quarter-wave line, properly matches the impedances of the antenna and the antenna cable, and provides a low standing-wave ratio along the cable. The antenna requires no adjustment.

HORN ANTENNA

An open-ended waveguide can be used to produce directional radiation. Some problems which occur are how to effectively match the waveguide to free space and how to achieve a narrow beam of radiation. Normally, the radiation pattern of an open-ended waveguide is broad in both the vertical and the horizontal planes. It is also an inefficient system because of the mismatch between the waveguide antenna and free space.

If the waveguide is flared out at a gradual angle as shown in figure 9-32 (A), a HORN antenna is obtained. The flare must be gradual so as to permit a better match between antenna and free space. At the same time, a sharper beam is obtained when a flared horn is used.

The horn is very practical at microwave frequencies since at these frequencies its physical size is not prohibitive. Since a resonant element is not involved, this type antenna is capable of wide-band operation. Horn antennas used in aircraft installations produce beam patterns that are not highly directive. In order to produce a highly directive beam the antenna would have to be longer than practical for aircraft. This disadvantage may be overcome by placing a LENS at the mouth of the horn.

For horn antennas as well as for dipole arrays and reflectors, a rule that may be kept in mind is that the larger the aperture of the waveguide or the larger the area of the array, the greater will be the gain and directivity. Since a large aperture is desired at the mouth, the length of the horn may become unwieldy if the gradual flare requirement is to be incorporated in the design.

A sectoral-type horn antenna is illustrated in figure 9-32 (A). Its field distribution is spherical in shape and depends upon the mode of operation of the waveguide feeding it and the flare angle of the horn. The spherical shape of the wavefront becomes flatter (elliptical) as the flare angle of the horn decreases. This horn has the greatest degree of directivity in the plane of the widest dimension.

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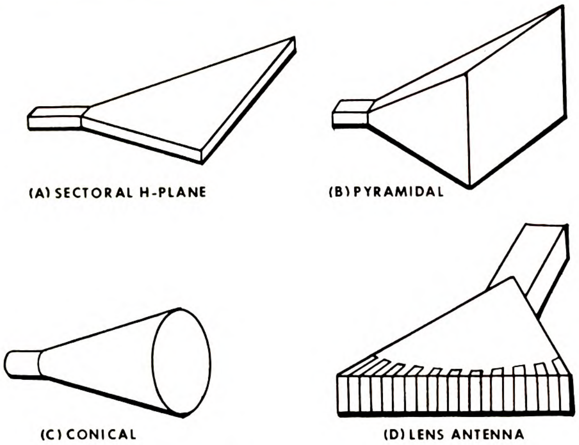
(A) SECTORAL H-PLANE
(B) PYRAMIDAL
(C) CONICAL
(D) LENS ANTENNA

Figure 9-32.—Horn antennas.

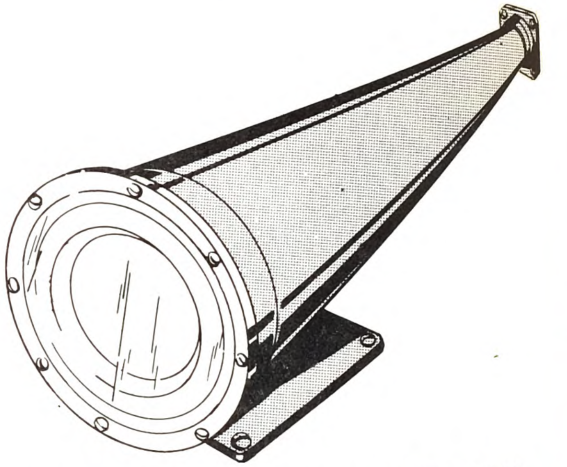

Figure 9-33.—Horn antenna with plastic-type lens.

Two other types of horns to which the principles just described apply are shown in figure 9-32 (B) and (C). The pyramidal horn (B) has equal directivity in both the vertical and horizontal plane. The conical horn (C) produces a conical beam pattern.

As previously mentioned, horn antennas are often fitted with a lens. These lens are made of plastic or conducting strips. When the lens is made of conducting strips, the strips are arranged parallel to the electric field and spaced slightly more than one-half wavelength apart. The wave entering the lens passes through the openings as though each opening is an individual waveguide section. (NOTE: The phase velocity of a wave traveling in a waveguide is greater than when traveling in free space.) A sectoral horn with a conducting-strip lens is shown in figure 9-32 (D). As you can see, the strips near the sides of the horn form longer sections of waveguides than those in the center. Thus, the wavefront will leave the horn in a plane of constant-phase since the phase velocity is progressively increased from the center of the horn toward the sides as the length of the individual waveguide sections increase.

The plastic-type lens, shown in figure 9-33, is affixed to a conical horn-type antenna. This particular antenna produces a beam width of 18 degrees at half-power points and has a gain of approximately 100. The lens is effective in reducing the sidelobe intensity by retarding the phase of the energy leaving through the center of the lens. This causes the energy to leave the horn in a plane of constant phase. It is interesting to note that while the two types of lens produce the same results they operate in somewhat opposite manner. The plastic lens retards the phase of the energy at the center and the conducting-strip lens accelerates the phase of the energy at the edge.

POLYROD ANTENNA

Figure 9-34 shows a polyrod antenna that consists of a slender, tapered rod of special plastic. This rod is cemented to a piece of standard waveguide that is flared to match the square dimension of the large end of the rod. The principal mechanical features of this antenna are its streamlined aspect, its small size, and light weight.

It can be shown experimentally that very high frequency radio energy can be made to travel along a rod made of material having good dielectric properties in much the same way as light travels along a lucite rod. Some of the light traveling along the lucite rod is emitted from its longitudinal surfaces. Similarly, some of the radiofrequency energy traveling along the dielectric rod is radiated from its longitudinal surfaces. However, by appropriately tapering the rod, the amount of energy radiated per unit length may be made approximately equal. In doing so, an end-fire antenna is created which is roughly analogous to a linear array of dipoles spaced a quarter wavelength apart and fed at successive 90-degree intervals. For such an antenna array, the net energy radiated broadside to the rod will be a minimum. The rod, as seen from a point in a forward direction, will appear to be radiating a cigar-like beam of energy.

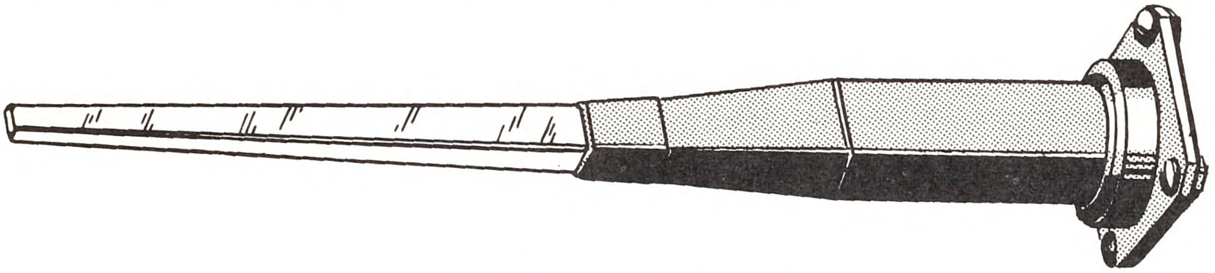

Figure 9-34.—A polyrod antenna.

It is interesting to compare the character-
ics of this antenna with those of the horn type
own in figure 9-33. While the half-power beam
idth of the horn is 18 degrees, that of the poly-
l is 25 degrees. However, the spurious radiation from the polyrod is of greater magnitude than that from the horn. These factors cause the polyrod to be less efficient than the horn, but nevertheless, in some applications, it is more desirable because of its mechanical features.

QUIZ

A ground plane is used with a vertical quarter-wave antenna when it is mounted several wavelengths above the ground to
- a. decrease the angle of radiation
- b. increase the angle of radiation
- c. decrease the antenna frequency range
- d. increase the antenna frequency range

Two advantages of the cosecant-squared reflectors are a/an
- a. wide vertical beam width and wide horizontal beam width
- b. narrow vertical beam width and narrow horizontal beam width
- c. wide vertical beam width and equal power to all targets
- d. wide vertical beam width and nearly equal target returns

The center input impedance of an omnidi-
rectional half-wave slot antenna will be
pproximately
- 72 ohms
- 50 ohms
- 530 ohms
- 1,000 ohms

n a horn antenna, the plastic lens reduces
idelobe power by
- retarding the phase of the energy leaving through the center of the lens
- retarding the phase of the energy leaving through the edge of the lens
- accelerating the energy leaving through the center of the lens
- stopping all energy leaving through the edge of the lens

5. A collinear array is two or more half-wave elements
   - a. mounted parallel to each other, spaced a half wave apart, and fed 180 degrees out of phase
   - b. mounted parallel to each other, spaced a half wave apart, and fed in phase
   - c. mounted along the same axis and fed 180 degrees out of phase
   - d. mounted along the same axis and fed in phase

6. Increasing the diameter of an antenna will
   - a. decrease its frequency range
   - b. increase its frequency range
   - c. increase radiation resistance
   - d. decrease its center impedance

7. The 10-cm. band would include which of the following frequencies?
   - a. 9,375 mc.
   - b. 2,880 mc.
   - c. 15,950 mc.
   - d. 300 mc.

8. A slot antenna, mounted horizontally, will produce a wavefront which is
   - a. horizontally polarized
   - b. vertically polarized
   - c. circularly polarized
   - d. not polarized

9. A driven array consists of
   - a. two or more driven elements
   - b. one driven element and one parasitically driven element
   - c. only one driven element
   - d. two or more parasitically driven elements

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10. A longer flare on a horn antenna will give
    a. decreased directivity and increased gain
    b. increased directivity and decreased gain
    c. increased directivity and increased gain
    d. decreased directivity and decreased gain

11. The angle formed by the one-half power points of an antenna lobe and the transmitting station is known as the
    a. radiation angle
    b. lobe angle
    c. beam angle
    d. antenna angle

12. To obtain the proper directivity in a parabolic reflector, it should have a diameter of
    a. a half wavelength
    b. a three-quarter wavelength
    c. many wavelengths
    d. a quarter wavelength

13. A broadside array consists of two or more half-wave elements
    a. mounted parallel to each other, spaced a quarter wave apart, and fed in phase
    b. mounted parallel to each other, spaced a half wave apart, and fed 180 degrees out out of phase
    c. mounted parallel to each other, spaced a half wave apart, and fed in phase
    d. mounted along the same axis, spaced a half wave apart, and fed in phase

14. The polyrod antenna can be compared to a
    a. Marconi antenna
    b. lucite rod
    c. half-wave center-fed antenna
    d. half-wave end-fed antenna

15. An end-fire array may consist of two or more half-wave elements
    a. mounted parallel to each other, spaced a quarter wave apart, and fed in phase
    b. mounted parallel to each other, spaced a half wave apart, and fed 180 degrees out of phase
    c. mounted parallel to each other, spaced a half wave apart, and fed in phase
    d. mounted along the same axis, spaced a half wave apart, and fed in phase

16. A diamond-shape antenna, operating at 1,000 mc., will have an approximate bandwidth of
    a. 200 mc.
    b. 50 mc.
    c. 400 mc.
    d. 100 mc.

17. An end-fed diamond-shaped antenna will have an input impedance of approximately
    a. 70 ohms
    b. 560 ohms
    c. 140 ohms
    d. 51 ohms

18. A parasitic array consists of
    a. two or more driven elements
    b. one driven element and one or more parasitically driven elements
    c. only one element
    d. all elements parasitically driven

19. The length of a ground plane should be
    a. one-third wavelength or less
    b. one-eighth wavelength or less
    c. one-quarter wavelength or greater
    d. exactly one-eighth wavelength

20. The advantage of a cone antenna over a thin wire antenna is its
    a. greater gain
    b. greater frequency range
    c. higher Q
    d. greater directivity

21. For optimum operation of a parasitic array, the spacing should be
    a. 0.15 wavelength for the reflector and 0.1 wavelength for the director
    b. 0.1 wavelength for the reflector and 0.15 wavelength for the director
    c. 0.4 wavelength for the reflector and 0.5 wavelength for the director
    d. 0.5 wavelength for the reflector and 0.4 wavelength for the director

22. The range of a half-wave skin antenna is approximately the same as a
    a. half-wave fixed-wire antenna
    b. quarter-wave fixed-wire antenna
    c. three-quarter-wave fixed-wire antenna
    d. full wave fixed-wire antenna

23. In a Yagi array, the
    a. director is about 5 percent shorter and the reflector about 5 percent longer than the driven element
    b. director is about 5 percent longer and the reflector about 5 percent shorter than the driven element
    c. reflector and director are about 5 percent longer than the driven element
    d. reflector and director are about 5 percent shorter than the driven element

24. The input impedance of a folded dipole (not a part of a parasitic array) is
    a. 36 ohms
    b. 72 ohms
    c. 144 ohms
    d. 288 ohms

CHAPTER 10

SERVOMECHANISMS

In the operation of electronic equipment it s often necessary to have the angular motion of shaft follow accurately the motion of another haft some distance away. If the shafts are not o far apart, the motion can be transmitted by neans of a mechanical linkage. However, when e shafts are not close together, this method ;, in general, cumbersome and uneconomical, rticularly where large amounts of torque and wer are to be transferred. A more flexible d more commonly used method is to convert e motion of one shaft into electrical currents, ansfer these currents via wires, and convert em back to mechanical motion of a second aft.

Two major applications of such conversions shaft motion to electrical currents and back shaft motion are remote indicator systems d servosystems. The term REMOTE INDI- TOR SYSTEM refers to a device used for nsmitting data or information between two nts. Examples are the reading of a meter l, the position of an antenna in azimuth or vation, temperature readings, and similar ormation. For such indications very little que and energy are involved. These systems included under the general term SYNCHRO STEMS and will not receive extensive coverage this chapter since they are covered in the y Training Course, *Basic Electricity*, Nav- s 10086-A.

Should you require a review of the theory of ious motors—single-phase, two-phase, and e-phase—you are again referred to *Basic ctricity*. If you are not familiar with the ns phase, split-phase, rotating field, torque, induction, then a review is indicated.

The term SERVOSYSTEM refers to a mech- m whereby a controlled shaft usually de- rs much more power than the controlling t, and the action of the power amplifying ce is regulated by the ERROR or dis- ancy in angular position between the two ts.

The term SERVOMECHANISM refers to a large variety of position control systems. It is frequently necessary to control the position of a device in accordance with some function of a signal supplied by a controlling instrument. If the power required to operate the device is large compared with the power available from the controlling instrument, power-amplifying means must be provided. When the amplification of the controlling signals is carried out by a machine or automatic device rather than by a human operator, the complete system is known as an AUTOMATIC CONTROL SYSTEM, and the element that amplifies the controlling signals and operates the device is known as an AUTOMATIC CONTROLLER. The servocontroller is the device in which the input is the error and the output controls the servomotor. This device is also known as a servoamplifier.

Automatic control systems can be divided into two types, depending upon the source of the signals that actuate the controller. If the signals supplied to the controller are determined not only by the controlling instrument but also by the position of the device being controlled, the system is known as a CLOSED-LOOP control system. This system is the one most frequently used since it is seldom possible to find a power-controlled mechanism in which the loop is not closed either mechanically or electrically. If the signals supplied to the controller are not a function of the position of the device being controlled, the system is known as an OPEN-LOOP control system. An example of the open-loop control system is the electric-type fuel gage on an automobile. The float in the fuel tank moves the arm of a potentiometer and causes the arm to pick off a voltage that is proportional to the height of the fuel in the tank. The gage is a simple voltmeter that indicates the amplitude of the voltage, thus the potentiometer movement is followed by a movement of the gage indicating needle.

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The term servomechanism is used to denote a certain type of closed-cycle automatic control system. If the controlling signals to the system change frequently and rapidly and the primary problem is to cause the controlled device to follow these signals, the system is called a SERVOMECHANISM. Servomechanisms are used to steer ships, to control airplanes, to automatically tune radio receivers, to position guns, in numerous telemetering and computing applications, and, in general, in those automatic control applications where accuracy of reproduction is of primary importance.

SERVOMECHANISM TERMS

The following terms have been applied to servomechanisms. The quantities defined are well established and, although they have not been standardized, are understood by those active in the field.

INPUT.—The input is the controlling quantity. It may be the displacement of a shaft, a voltage or current, a temperature level, and so forth.

OUTPUT.—The servo output is the position or state of the controlled quantity. It may be any of the quantities listed in the definition of the INPUT.

ERROR.—The servo error is the difference between the servomechanism input and the output. An error is introduced each time the controlling quantity is changed.

ERROR DETECTOR.—The error detector is the device which compares the input with the servomechanism output.

SERVOCONTROLLER.—The servocontroller is the device in which the input is the error and the output controls the servomotor.

SERVOMOTOR.—The servomotor is the prime mover of the servomechanism. It is actuated by the servocontroller and controls the servo load or output.

SERVO LOAD.—The servo load is the quantity upon which the servomotor operates.

COMPONENTS OF AN ELECTROMECHANICAL SERVOMECHANISM

The essential components of a servomechanism are the data transmission system, the servocontroller, and the servomotor. These components are shown in the block diagram of figure 10-1. The function of each component will be discussed. While the servo load, strictly speaking, is not a component of the servomechanism, its characteristics have an important bearing on the design and operation of the servosystem.

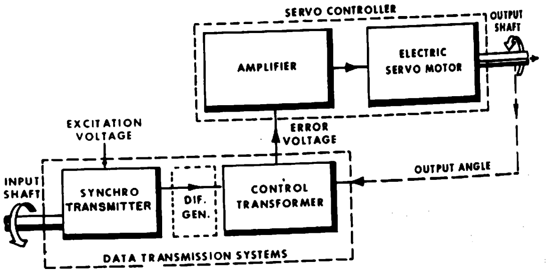


Figure 10-1.—Simplified block diagram of a servomechanism.

Data-Transmission Systems

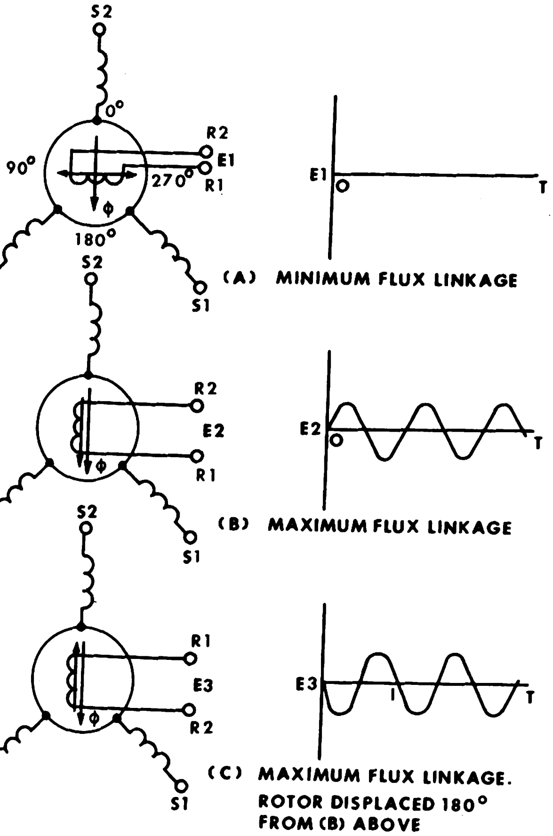
In some servomechanisms the data-transmission system may consist solely of an error detector (control transformer). In many servosystems, both the physical position of the servo output and the origin of the signals comprising the servo input may be remote from one another and from the servocontroller. The function of the data-transmission system is to transmit a signal from the input synchro transmitter to the control transformer. This signal is combined with the servo output in the error detector (control transformer) which determines the magnitude and direction of error. This error signal is then applied to the servocontroller.

One component of the data-tranmission system is the error detector which is the mechanism for comparing the input and output functions. The error detector may be resistive (potentiometer), capacitive, or one of several types of magnetic devices.

A commonly used magnetic error detector is the synchro. The synchro has been developed to the point that it is characterized by relatively high accuracy, low noise level, reasonably small driving torques, and excellent life. A primary advantage over other types of error detectors is its unlimited rotation angle; that is, both the input and the output to the synchro may rotate through unlimited angles.

The synchro data-transmission system is comprised of a synchro transmitter, a synchro control transformer, and in some cases a differential generator. (See *Basic Electricity*, JavPers 10086-A, for the theory of operation ınd function of a differential generator.) The ynchro transmitter transforms the motion of ts shaft into electrical signals suitable for ransmission to the synchro control transormer which comprises the error detector.

The stator of the generator consists of three oils spaced 120 electrical degrees apart. The oltage induced in the stator windings is a ınction of the position of the salient pole enerator rotor. These voltages are applied to ıe three similar stator windings of the synchro ontrol transformer. The voltage induced in the otor of the synchro control transformer deends upon the relative position of this rotor ith respect to the direction of the stator flux. ıe variation of the synchro control transformer itput voltage as a function of the rotor position lative to an assumed stator flux direction is own in figure 10-2. While there are two sitions of the rotor, 180 degrees apart, where output voltage is zero, only one corresponds a stable operating position of the servo.



(A) MINIMUM FLUX LINKAGE

(B) MAXIMUM FLUX LINKAGE

(C) MAXIMUM FLUX LINKAGE. ROTOR DISPLACED 180° FROM (B) ABOVE

igure 10-2.—Induced voltage in synchro control transformer rotor.

Another type of error-detecting element commonly used in the data-transmission system is the potentiometer. Potentiometers are generally used only where the input and the output of a servomechanism have limited motion; they are characterized by high accuracy, small size, and the fact that a d-c or a-c voltage may be obtained as the output. Their disadvantages include limited motion, a life problem resulting from the wear of the brush on the potentiometer wire, and the fact that the voltage out of the potentiometer changes in separate steps as the brush moves from wire to wire. A further disadvantage of some potentiometers is the high-driving torque required.

Capacity devices have not been widely used to date as error-detecting devices in servomechanisms.

Multiple-Speed Data-Transmission Systems

The static accuracy of a servomechanism is frequently limited only by the accuracy of the data-transmission system. The accuracy of the data-transmission system may be increased considerably by employing a multiple-speed data-transmission system along with the single-speed system. The error-detector elements of the multiple-speed transmission system rotate at some multiple of the shaft being controlled, while the elements of the single-speed transmission system operate one to one with respect to the controlled shaft.

The schematic diagram of a multiple- and single-speed system is shown in figure 10-3. If the input shaft turns through 1 degree in this example, the single-speed synchro transmitter also is rotated 1 degree while the multiple-speed unit is rotated 10 degrees. The synchro control transformer associated with each of these transmitters is geared in similar ratios with respect to the servo output shaft. A 1-degree error between the positions of the input and output shafts therefore produces a relative rotor displacement of 1 degree in the single-speed synchros and 10 degrees in the multiple-speed synchros. If the relation between the rotor displacement and output voltage is linear, the error signal from the multiple-speed system is ten times that from the single-speed system. This amplification of the error signal in the data-transmission link reduces the signal amplification required in the servocontroller. If the synchro has an inherent error of 0.1 degree

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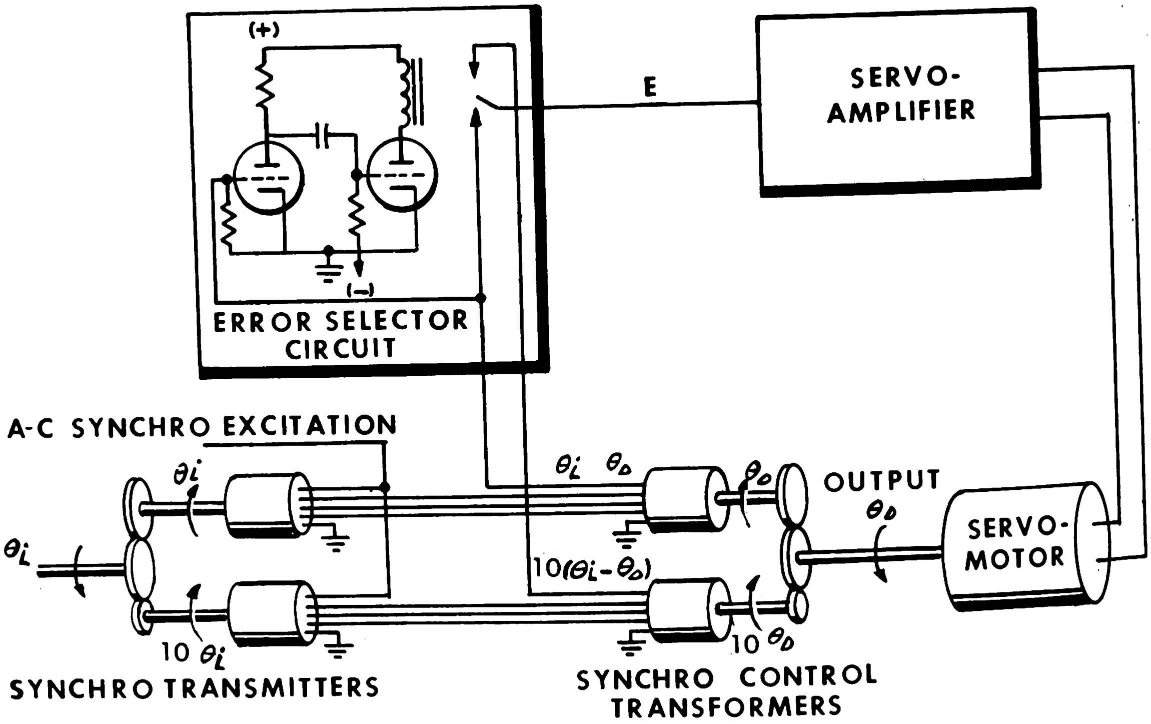

Figure 10-3.—Multiple-speed synchro data-transmission system.

with respect to its own shaft, the consequent servo error introduced by a single-speed data-transmission system will be of corresponding magnitude, but the consequent servo error introduced by a 10-speed data-transmission system will be only one-tenth as great or 0.01 degree.

A disadvantage of using a multiple-speed error detector lies in the possibility of the system falling out of step and synchronizing in a position differing from the correct position by an integral number of revolutions of the multiple-speed synchro. In the example shown in figure 10-3, if the output shaft were held fixed and the input shaft rotated 36 degrees, the 10-speed synchro transmitter would turn through one complete revolution. At this point the error signal from the multiple-speed error detector would be zero. If the output shaft were then released, the system would operate in stable fashion with a 36-degree error between the input and output shafts. The purpose of using a single-speed error detector along with the multiple-speed detector is to prevent this ambiguous synchronization. In this example the ambiguity is prevented in the following manner.

An error-signal-selector circuit is provided which switches control of the servo to the single-speed data system whenever the servo error becomes large enough to permit the multiple-speed system to synchronize falsely. The type of error-selector circuit shown in figure 10-3 is frequently used. It is essentially a single-pole double-throw relay actuated by the output of the single-speed error detector. This relay switches control to the single-speed synchros whenever the servo error exceeds about 12 degrees, which corresponds to 120 degrees of error displacement of the multiple-speed synchro rotors.

With the error-signal-selector circuit shown, it is still possible to have a single ambiguous synchronizing point in the system, because the multiple-speed synchros operate at an even multiple of the single-speed synchros. This ambiguous synchronization can occur when the servo input and output shafts are 180 degrees out of phase. In this position both the single- and multiple- speed synchro systems are at null voltage positions and control of the system is retained by the multiple-speed units. One way of eliminating this false synchronization position by operating the multiple-speed synchros at odd multiple of the single-speed synchros. ile the 180-degree null position of the single-eed synchros still coincides with a null tage position of the multiple-speed synchros, corresponding servo position is an unstable e and the servo will not remain at this point.

The disadvantage of using multiple-speed or detectors is the need of an additional chro system and switching circuit if false chronization is to be avoided. The increased vo accuracy resulting from the amplification the error signal and the effective reduction inherent synchro errors, however, account the wide use of these multiple-speed data tems.

Servoamplifiers

The functions of the servoamplifier are:

1. To supply required amplification of the error signal.
2. To transfer the error signal into suitable form for controlling the servomotor.
3. To provide special characteristics that may be necessary to obtain stable, fast, and accurate servo operations.

Every servoamplifier provides one of these tions and many provide all three. A block ram of a servoamplifier which performs all e of these is shown in figure 10-4. The t to this amplifier is represented as an signal, the magnitude of which is pro-ional to the magnitude of the error between input and the output and the phase of which function of the sine of the error. The first on of the servoamplifier is an a-c amplifier supplies the gain necessary for proper ation of the system. The second component is amplifier is a sense-detecting rectifier emodulator. This element transforms the rror signal into a d-c signal, the magnitude ich is proportional to the magnitude of the error and the polarity of which is de-ned by the direction of the servo error. inal component of the amplifier is a d-c amplifier that raises the d-c signal to the power level necessary to control the servomotor.

In many control systems the servoamplifier is not required to perform all of the functions indicated in the amplifier shown in figure 10-4. For example, if the servomotor is to be controlled by an a-c voltage of the same frequency as the a-c error signal, the detector and rectifier might be eliminated and the d-c modifying network replaced by a-c networks or by devices that produce the desired effect in other ways.

Thus the functions of the servoamplifier and its exact form may vary widely in different control applications. Examples of actual amplifiers are given in other sections of this chapter.

Servomotors

The function of the servomotor is to supply the torque, power, and dynamic characteristics required to position the servo load satisfactorily. The servomotor itself is controlled by the servoamplifier. Ideally, a servomotor should require only small amounts of power from the amplifier, should be capable of accelerating rapidly, reversing direction readily, and should be characterized by small size and weight, long life, small time lags, and an adequate speed range. Some of the electric motor types frequently used in servomechanisms are indicated as follows:

The 2-phase induction motor is the most widely used a-c servomotor. One phase of this motor is excited from a constant reference source; the other phase is excited in quadrature (at right angles) with this reference phase by the servoamplifier output. The motor torque is proportional to the amplitude of the control voltage and its direction depends on the relative phase of the excitations on the control and reference phase.

The most frequently used d-c servomotor is the separately excited shunt motor. Its direction of rotation is usually controlled by controlling the direction of current flow in two separately excited differentially wound field coils. This

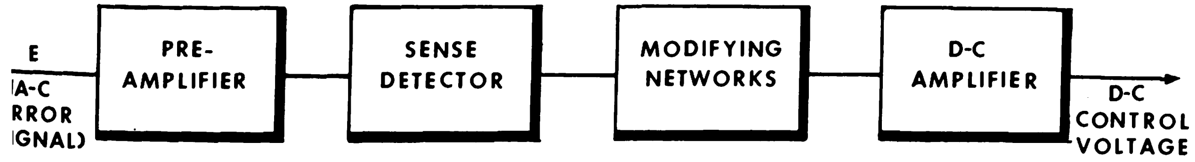

Figure 10-4. —Block diagram of servo-amplifier.

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arrangement facilitates the direction control of the field current by the servoamplifier. The voltage applied to the armature (line voltage) is regulated in order to maintain a linear relationship between the motor output torque and the field current. The field current to the servomotor will be supplied from a servoamplifier using an output such as the discriminators that follow.

Certain types of shaded-pole induction motors have been developed which are also suitable as servomotors, but which are not widely used at present. In each of these motors the main field winding usually is excited from a constant a-c source and the motor output-torque amplitude and direction are controlled by an alternating voltage and direct voltage applied to a shading winding. The alternating control voltage is either in phase or 180 degrees out of phase with the main field voltage. As in the case of the 2-phase induction motor, the sense detector may be unnecessary if a synchro error detector is used in the servosystem.

Universal motors and clutch mechanisms are sometimes used as servomotors, but in general they have not been applied as extensively in control systems as the types of motors mentioned.

CIRCUIT FUNCTIONS AND ANALYSIS OF SERVOAMPLIFIERS

Phase Discriminators

A phase discriminator or, as it is sometimes known, a phase sensitive rectifier, will mix two a-c voltages and provide a d-c control voltage or current of reversible polarity at the output. The two voltages to be mixed will in most applications be either in phase or 180 degrees out of phase.

DIODE PHASE DISCRIMINATOR

A typical diode phase discriminator is shown in figure 10-5. As illustrated, an a-c excitation voltage serves as the reference voltage to the discriminator. This voltage must come from the same source supply that is supplying a-c excitation to the synchro system that will create

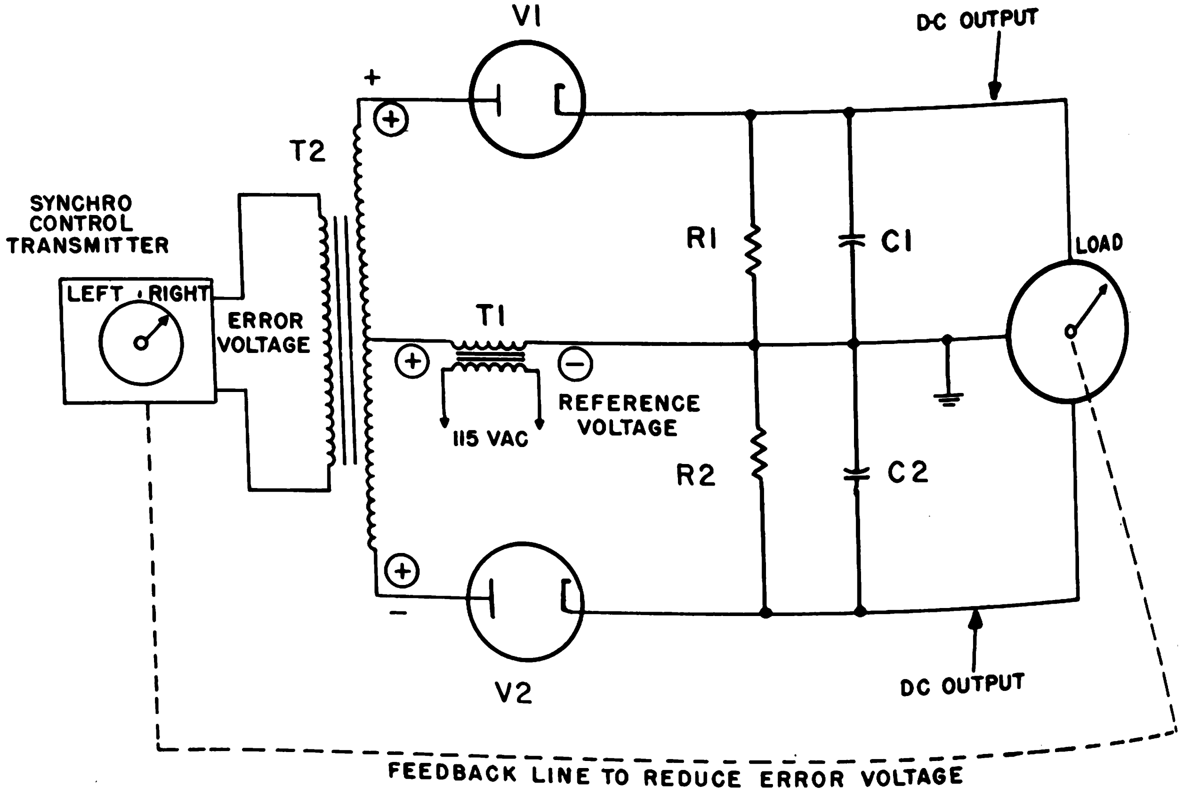

Figure 10-5.—Phase sensitive rectifier using diodes.

the voltage to be compared to the reference (error voltage). The plates of the two diodes are supplied with this reference voltage in such a manner that the two plates will be in phase. Assuming that there is no error signal from T2 into the plates of the diodes at the time the plates are on a positive half cycle, the two diodes will conduct equally. The voltage produced across R1 and R2 are at equal potential n respect to ground. The a-c component is removed by capacitors C1 and C2. The output s zero as long as no signal is introduced by T2.

The circuit of figure 10-5 shows the polarities f the two voltages present at the diode plates t a given instant. The polarity of the reference oltage is shown encircled to differentiate etween it and the error voltage. The error oltage is produced by a synchro control transormer which will be positioned manually when ne load is to be repositioned.

The reference voltage is applied to the diode lates through the centertap of T2, thereby ppearing at both plates in the same polarity. owever, when the synchro control transformer ointer is turned, the error voltage appears cross the entire secondary winding and is pplied to the diode plates in opposite polarity. the figure, V1 is shown as having two positive ltages applied to its plate, while V2 exriences a positive and a negative voltage. 1 will conduct more than V2, charging C1 to higher voltage. Conversely, if the error ltage and the reference voltage appeared at plate of V2 instantaneously positive, then would experience a positive and a negative ltage, and V2 would conduct more than V1. that event, C2 would charge to a higher tage than C1.

Note that V1 and V2 feed their outputs to the d, and that a feedback line from the load nects to the control transformer. When an or voltage is introduced through T2 one of diodes will conduct more than the other and load will rotate in one direction. If the or voltage is reversed in polarity then the d will rotate in the opposite direction. The tional speed of the load is determined by the ount of voltage applied to it, which in turn is rmined by the magnitude of the error voltage. greater the number of degrees the control sformer pointer is displaced from its static tion, the greater will be the error voltage the faster the load rotation. As the load ns to rotate to its newly indicated position a back voltage is applied to the control transformer. The feedback voltage progressively reduces the error voltage to zero as the load assumes its new position.

Recall that the reference voltage and the synchro that produces the error voltage are supplied by the same source of a.c. These two voltages will, therefore, switch polarities at the same time; that is, when the error voltage on the plate of V1 switches from positive to negative, then the reference voltage at V1 will have switched from positive to negative also. At that instant V2 will experience a positive error voltage polarity and a negative reference voltage polarity. Neither tube will conduct an appreciable amount. On the next half-cycle switch the polarities will again be as indicated in figure 10-5 and V1 will conduct. Since the capacitors C1 and C2 charge to the average of the voltages applied, then the capacitor associated with the tube that conducts the most will charge to the highest voltage.

The tube that conducts the most will be the one that has both applied voltages instantaneously positive, and will be the one that determines the direction of load rotation.

TRIODE PHASE DISCRIMINATOR

A phase discriminator using triode tubes is shown in figure 10-6.

In this circuit, as in the previous one, the plates of the tubes are supplied with the a-c reference voltage in such a manner that the plates will be in phase. For purpose of explanation assume that no error signal is present at T2. When the plates of V1 and V2 are positive, the two tubes will conduct equally. The plate current that flows will set up fields in the d-c motor control windings that will be equal and opposite; therefore, the fields will cancel and produce no output. When the plate voltages are on a negative half cycle, C1 and C2 will be discharging through their respective control windings to maintain a constant d-c current through the windings.

If an error signal is introduced into the primary of T2 of such a phase relationship that the grid of V1 will be positive at the same instant that the plate of V1 is positive, the following conditions will exist:

1. On this half cycle the conduction of V1 will be increased above its static value.

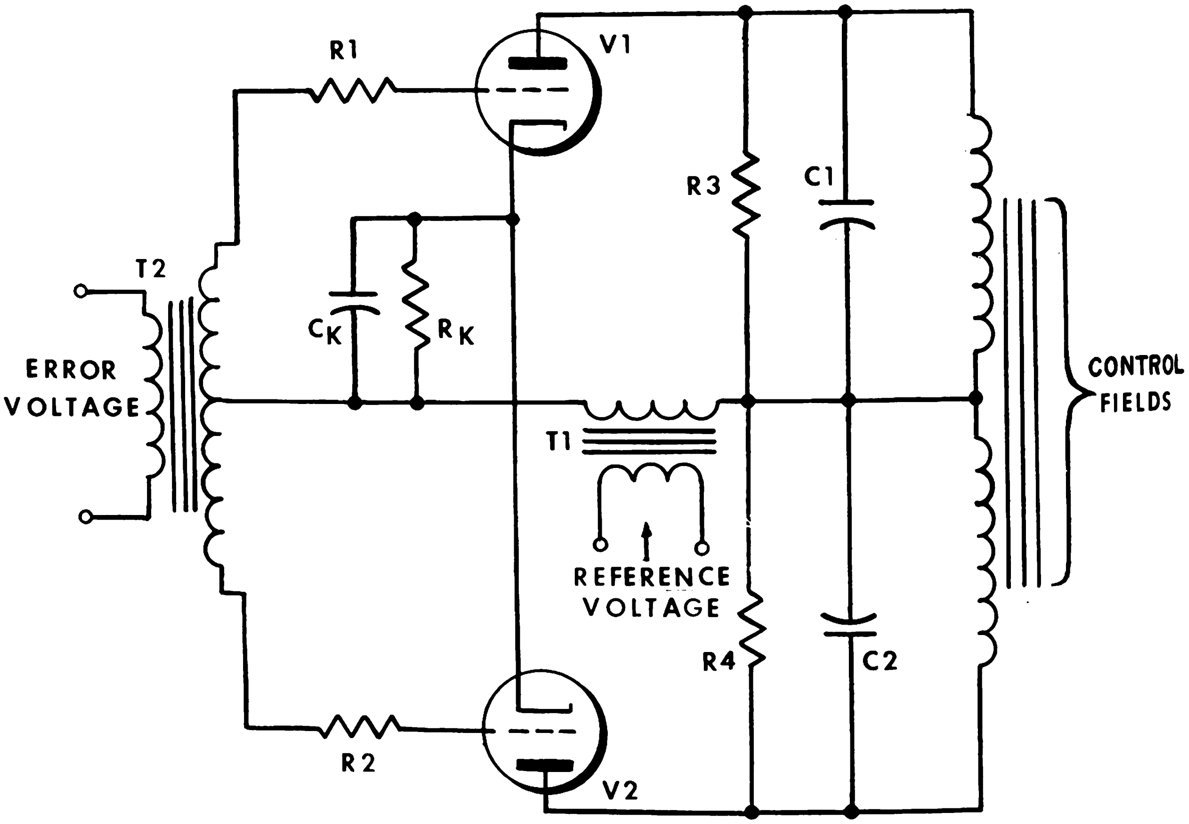

Figure 10-6.—Servoamplifier.

2. The heavier plate current will cause a stronger field to be created in the upper control winding.
3. At this same instant, since the grid of V2 is on a negative half cycle, its average conduction will be reduced to a level below that of its static value.
4. The lower level of plate current will cause a weaker field to be produced in the lower control winding.
5. Since the magnetic fields produced in the control windings are no longer of equal amplitudes, they can no longer cancel each other.
6. The control windings will produce an output voltage of a polarity controlled by the polarity of the resultant field and of an amplitude controlled by the relative strength of this resultant field.
7. The control output will cause the proper mechanical actions necessary to reduce the amplitude of the error to zero.
8. As the error signal is reduced to zero, the current conduction through V1 and V2 will again be balanced and the control fields will be equal and opposite and cancel each other, reducing the control output to zero and stopping the mechanical action. Resistors R1 and R2 prevent excessive grid current when the error angle is large.

FULL-WAVE DIODE BRIDGE DISCRIMINATOR

A tilt control circuit using a full-wave diode bridge discriminator is illustrated in figure 10-7. This discriminator consists of tubes V3 and V4 and associated circuits.

This circuit will produce a d-c voltage with its polarity controlled by the phase relationship of the input error signal with respect to the reference voltage. The amplitude of the d-c output control voltage will be determined by the amplitude of the error signal.

Assuming no error signal is present the circuit will perform as follows:

At the instant when the voltage at terminal 3 of T4 is negative and terminal 5 is positive,

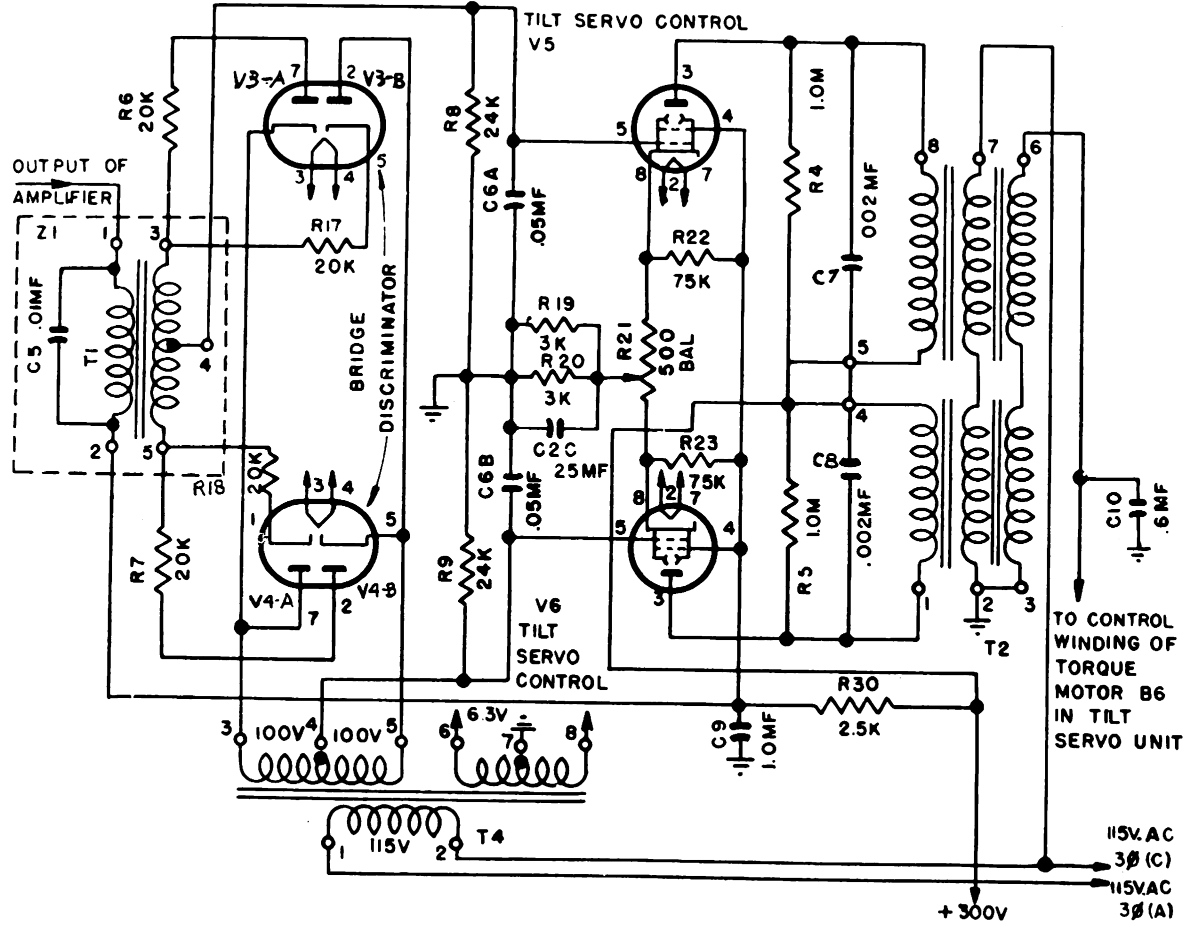

Figure 10-7.—Discriminator and tilt-servocontrol circuit.

ent will flow from terminal 3 to the cathode 3-A and then to its plate. From the plate 73-A it flows through R6 to terminal 3 of and through R17 to the cathode of V3-B, igh the tube and back to terminal 5 of T4. he alternate half cycle when terminal 3 of s positive and terminal 5 is negative, current flow from terminal 5 of T4 to the cathode 1-B, through the diode to R7 and to terminal T1, from terminal 5 of T1 through R18 to cathode of V4-A, through V4-A back to inal 3 of T4. Note that during this entire no current will flow through R8 and R9, currents tend to flow in both directions THE SAME TIME. They are equal and site; thus, they cancel and the voltage ss the output terminals will be zero.

n error signal introduced into T1 will be definite phase relationship with respect to eference voltage; it will be either in phase or 180 degrees out of phase. If it is assumed that terminal 3 of both T1 and T4 are in phase and on a positive half cycle, current will flow as follows: From terminal 5 of T1 through R18 and V4-A (cathode to plate), to terminal 3 of T4 then to the center tap terminal 4 of T4. From terminal 4 of T4 through R9 and R8 to the center tap terminal 4 of T1 and back to terminal 5 of T1. On the alternate half cycle, terminal 3 of both transformers will be negative. Current will then flow from terminal 3 of T1 through R17 and V3-B (cathode to plate), to terminal 5 of T4 to the center tap terminal 4. From terminal 4 of T4 through R8 and R9, on to terminal 4 of T1 and back to terminal 3 of T1. For a complete cycle current has passed through R9 and R8 as a d-c current, causing the bottom end of R9 to be negative in respect to the top of R8. C7 and C8 will remove any a-c component of voltage which may appear at

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the output. If terminal 3 of T1 and T4 had been out of phase, the direction of current flow through R9 and R8 would have been in the opposite direction, so that the output polarity of voltage would have been reversed.

Induction-Motor Type Servosystem

A 2-phase induction motor is frequently used with servosystems in aviation installations. Figure 10-8 illustrates by way of a block diagram a basic circuit using this type motor.

The action that takes place is as follows: An alternating voltage of fixed amplitude is applied to coil A. Capacitor C is connected in series with coil A for the purpose of providing a phase shift so that the voltage applied to this coil is nearly 90 degrees out of phase with the synchro voltages. Thus, the output of the servo-amplifier, which is connected to coil B, will be 90 degrees out of phase with coil A. This action provides the necessary phase difference between the coils for proper operation of the motor.

When the input and output shafts are displaced from each other an error voltage will be produced. As a result of this error voltage, the servoamplifier will supply a current to coil B. This current, in conjunction with coil A, produces a rotating flux that drives the induction motor in the direction to reduce the error to zero.

When the error voltage is zero, only coil A will produce a magnetic flux in the induction motor. Since this alternating flux does not rotate, no torque is produced by the motor and rotation stops.

The servoamplifier in this circuit functions as an audio amplifier. It provides an amplified output of the error voltage that is in phase with the error voltage.

Antihunt Devices

Servomechanisms and associated amplifiers will necessarily have high-power gain in order to provide fast response from input to output shaft. Servomechanisms must be capable of supplying sufficient power to create high enough torque to overcome load inertia and insure accurate controlled motion. A servo that does this causes the output shaft to approach a new position at a high rate of speed. When the output shaft reaches the correct position at full speed, mechanical inertia will cause it to run beyond the correct point, commonly called OVERSHOOT. This overshoot creates an error signal of opposite phase at the servo input which causes the motor rotation to reverse the

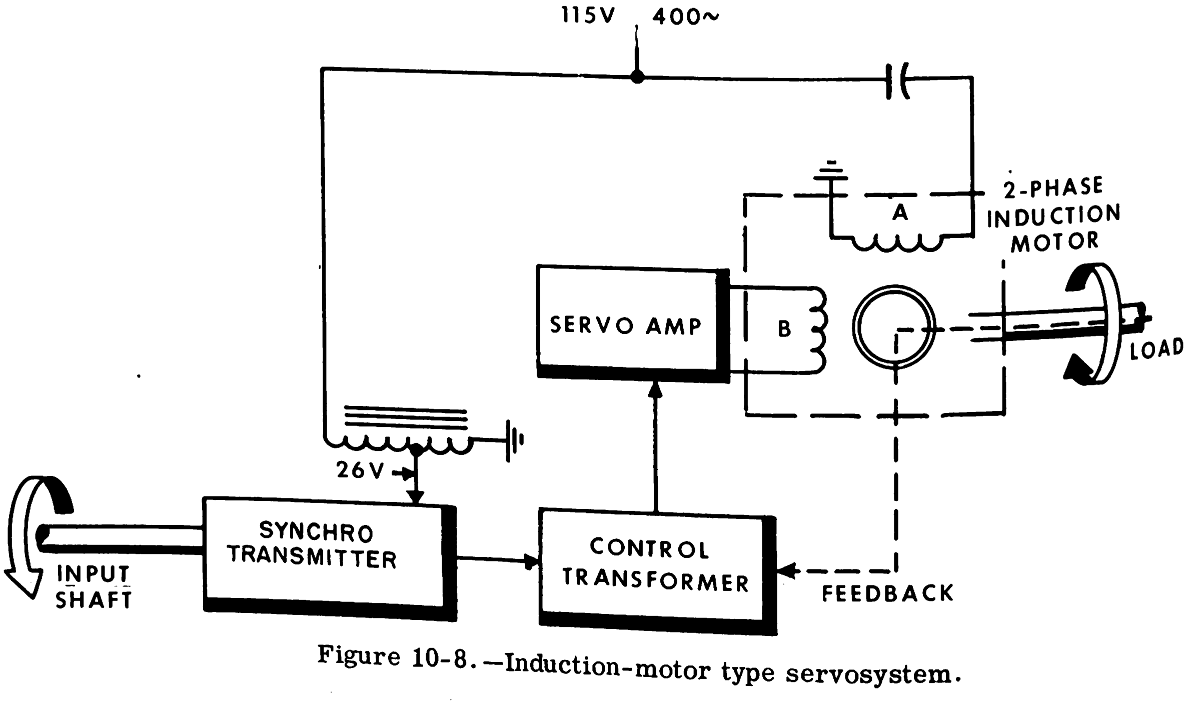


Figure 10-8.—Induction-motor type servosystem.

put shaft's direction. The results of this ion are:

1. The reversed motion drives the output shaft back through its correct position.
2. Motor rotation will again reverse to the original direction.
3. The amplitude of output shaft motions will gradually decrease each time it passes through its correct position.

s oscillation is usually termed HUNTING. It st be prevented so as not to cause damage the output shaft's mechanical components. o, since the output shaft may take a relatively g time to stop or dampen out these oscillons, this hunting will with all probability ult in very poor servo operation.

CHANICAL FRICTION METHOD

One method of creating antihunt action is to ate a high mechanical friction on the output ft, but this system has many disadvantages. y are:

1. Much of the servomechanism output power is lost in frictional heat, thus creating a a very inefficient system.
2. Such a system requires much heavier and larger mechanical components.
3. The positioning of the output shaft is less accurate.
4. The degree of error between input and output shaft is quite large.
5. The speed of the output shaft is slower than that desired of an efficient servosystem.

RTIA DAMPERS

nertia dampers such as are used on synchro ivers are practical only on the very smallest ervosystems. This is true because the ia of the damper must be many times that e output shaft and its mechanical load in r to dampen oscillations effectively.

TER-TYPE ANTIHUNT DEVICE

simple electrical means of antihunt is to oy a limiter in the error amplifier ahead e discriminator. A very low plate supply ge applied to one of the error voltage ifier stages will limit the gain of the stage to a very low level. In such a system a low amplitude error signal produces an amplified output. This output gives a definite speed of output shaft motion which is comparatively low. Increasing the error signal amplitude causes no further increase in output because of the limiting action of this amplifier stage. The motor and output shaft speed will thus have no increase. The output shaft speed will necessarily be quite slow and the mechanical load will be great enough to prevent overshoot. The main disadvantage of this system is: It causes very slow response to an error angle between input and output shafts due to the low servo gain. This form of antihunt has been used with azimuth stabilization systems where output speed need not be fast.

HIGH-SPEED ANTIHUNT DEVICE

Figure 10-9 illustrates a radar's tilt-stabilization system which contains a high-speed antihunt device.

An a-c generator is geared mechanically to the tilt torque motor and has an output voltage when the torque motor turns. This is the damping signal generator shown in figure 10-9. The a-c voltage out of this generator is adjusted to a value equal to the error signal produced with only a few degrees of angular displacement between input and output shafts. This ANTIHUNT or DAMPING voltage is fed to the servoamplifier in such a manner as to be out of phase with the error voltage at all times. As the servo torque motor turns the output shaft to its new position, the amplitude of error signal will be constantly decreasing to a null of voltage. At some point close to zero angular displacement between input and output shafts, the antihunt a-c voltage will be equal in amplitude but out of phase with the error voltage, so that the signal into the servoamplifier is canceled. The inertia of the output shaft mechanism carries the output shaft beyond this point to where the phase of the amplifier input signal is reversed and starts to increase in amplitude due to the damping signal generator's output exceeding the error signal. This causes a reversal of the output voltage from the servoamplifier to the torque motor prior to reaching a null of the positional error voltage. This reversal of torque causes a braking action which stops the torque motor and the load. This

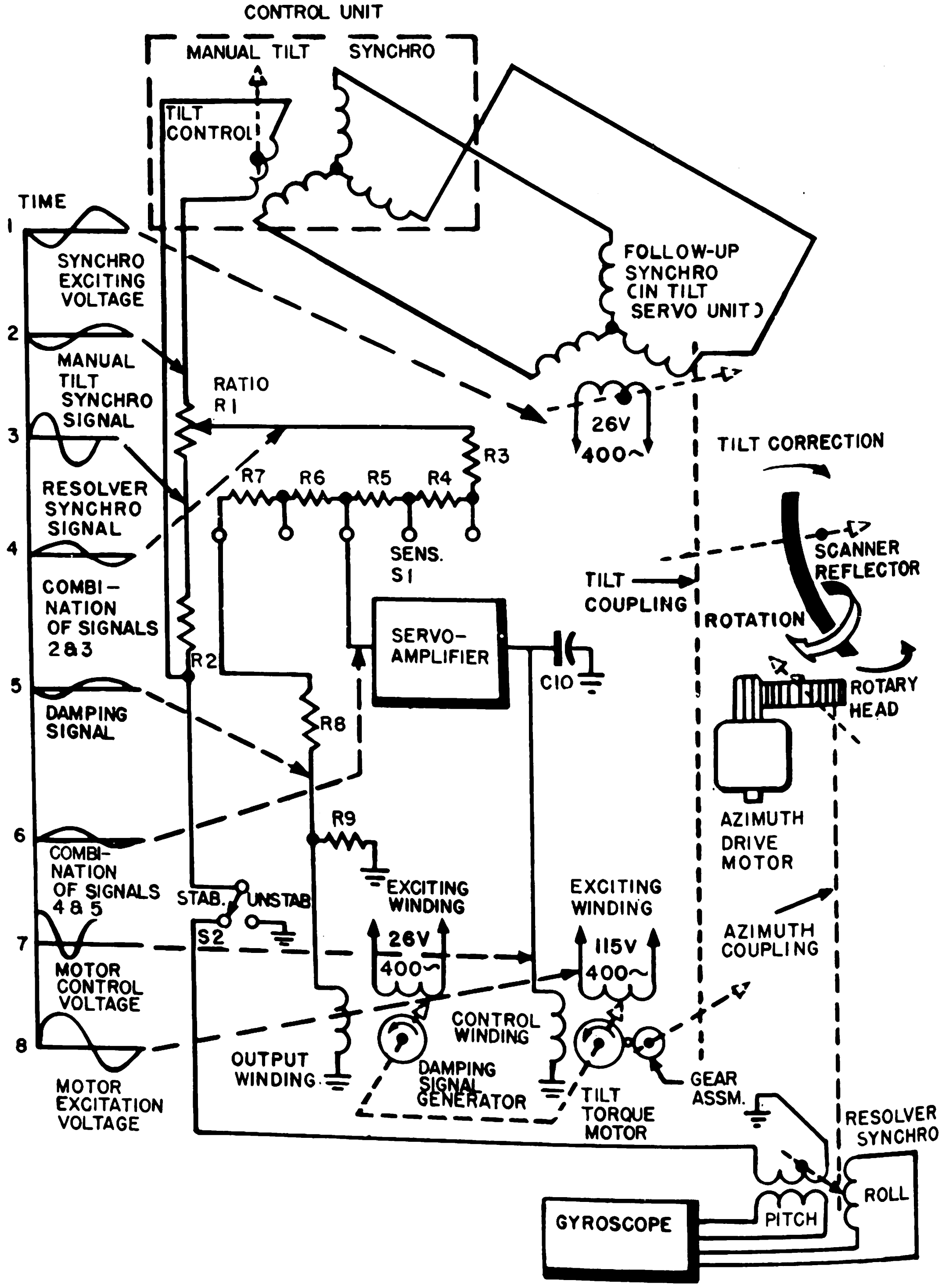


Figure 10-9.—Tilt stabilization with high-speed antihunt.

so stops the damping signal generator and no ther error is applied to the amplifier.

Some provision must be made to control the act amplitude of the net input signal to the rvoamplifier so that optimum stability is ained. This may be done by varying the ihunt or damping generator output so as to cel out the error signal at the proper angular placement.

If the antihunt or damping signal is LOW in plitude as compared to the error signal at correct cancellation angle, the power to the que motor will not be removed at the proper ular displacement point. This will cause the put shaft to overshoot the proper angle and illations or hunting will occur. These oscil- ons will gradually diminish to the correct ition of the output shaft. If the antihunt or ping signal is HIGH in amplitude as com- ed to the error signal at the proper can- ation angle, the error signal will be cancelled oo great an error angle, or too soon. The ut shaft will be stopped with some degree rror angle remaining between input and ut shafts. As the output shaft stops, the a-c ping voltage will fall to zero and the re- ing error signal will cause the shaft to slowly to the correct point.

IVATIVE TAKING ANTIHUNT NETWORK

derivative taking network used as an unt device is shown in figure 10-10. The uit shown is the first voltage amplifier in rvoamplifier used to drive a 2-phase tion motor. The derivative network Z1 ists of C1 and L1.

his network is a high-impedance series- nant circuit which suppresses hunting and shoot caused by the inertia of the following m. This is accomplished by introducing a lead in the servosystem. During the re- ls which are characteristic of sector-scan tion in a radar azimuth servosystem, the required to overcome the lag in the sys- s quite high.

e rotor output of the synchro control ormer is fed through voltage dividing or R2 to the mesh composed of resistor parallel with capacitor C1 and inductor he reactive elements form a series- ant branch at the supply frequency and very low impedance. At any other fre- , they appear inductive or capacitive and cause the output of the derivative network to lead in phase, thus the load anticipates any change in input speed and direction.

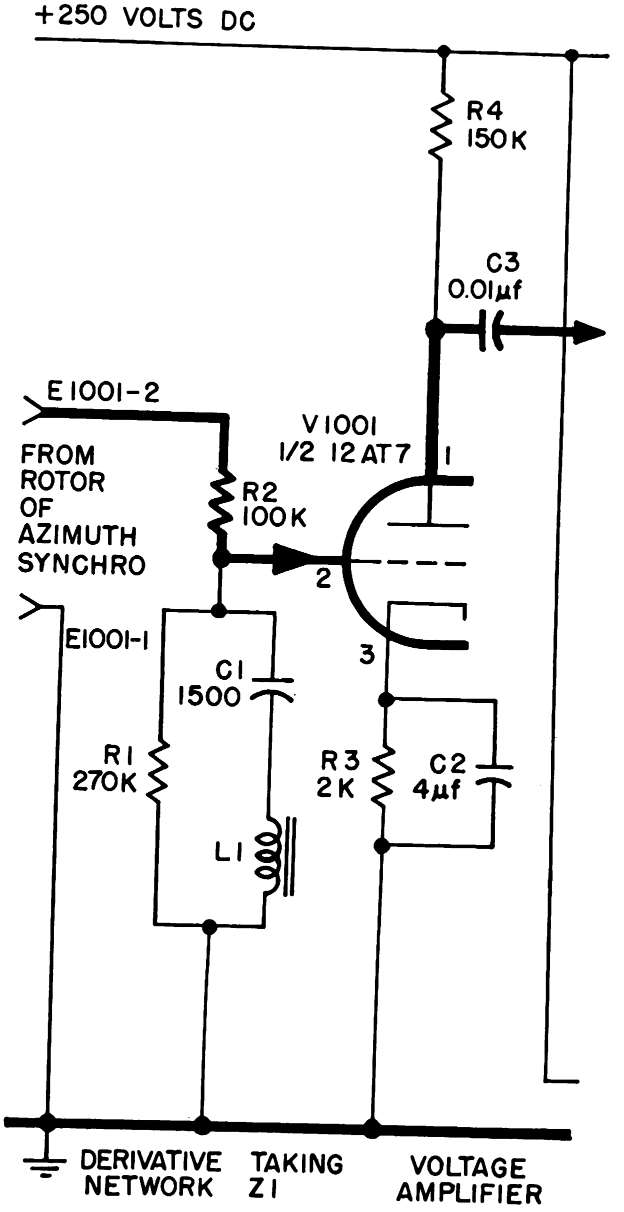


Figure 10-10.—Derivative-taking network.

Review of a Servomechanism System

As you review the operation of a servomechanism system, use figure 10-1 as a reference. The connections and functions of the basic servomechanism components are as follows: Consider that when the input shaft is turned, an error voltage is produced. This voltage is taken from the rotor of the control transformer and applied to some type of servoamplifier. The amplifier will supply power to the servomotor which will turn the output shaft. The output shaft will position the load device, and is also mechanically connected back to the control transformer.

The basic operating sequence is as follows: When the input shaft is moved, a pattern of voltages will be transmitted by the synchro generator to the control transformer stators. An error voltage will be supplied to the amplifier from the control transformer rotor. The phase of this voltage with respect to the reference voltage depends upon which direction the input shaft is turned. The amplitude depends upon the amount of displacement between the input and output shafts. The servoamplifier develops a control voltage or current of the proper phase and amplitude to be applied to the control winding or windings of the servo. The control circuit will cause the servomotor and control transformer rotor to turn in the same direction and the same number of degrees as the input shaft has been turned. Once the rotor position of the control transformer differs from the synchro transmitter rotor position by 90 degrees, the input to the amplifier is zero and the system returns to a static state.

Servomechanism Adjustments

It is important that you know how to make the proper adjustments to servomechanisms in order to obtain from them the proper performance. Adjustments must be made when new equipment is installed, when components such as control transformers, differential synchros, servoamplifiers, tubes, or other parts of the servosystem are replaced, and during normal service as a result of variations in the system due to the usage of the parts. These adjustments will provide changes in gain, phase, and balance of the servoamplifier and also the alinement or zeroing of the synchros of the system. The zeroing of synchros in general has been covered in *Basic Electricity*, NavPers 10086-A and will not be covered in this chapter. The specific instructions for zeroing the synchros of each specific type equipment will be found in the *Handbook of Service Instructions* for that equipment.

PHASE ADJUSTMENT

After the servosystem has been zeroed or alined, it is then necessary to ascertain if the phase relationships are correct. Phase shift adjustments are frequently provided in a servosystem to compensate for any undesirable phase shift caused by the amplifier or the synchro data-transmission system. When a system uses a 2-phase servomotor, the controlled winding voltage must be 90 degrees out of phase with the fixed voltage winding. Many servosystems provide a means of adjusting the phase difference between these voltages. There are various methods of making this adjustment. Some equipments provide a means of adjusting the phase of the fixed voltage winding. This is accomplished by varying the capacitor that is connected in series with the fixed voltage winding. Other servosystems use an amplifier that contains a variable RC or RL network which, when adjusted, varies the phase of the controlled voltage winding.

An improper phase difference may be detected with an oscilloscope. The procedure involves the well-known Lissajou patterns. Two alternating voltages to be compared are applied to the horizontal and vertical plates. The resultant Lissajou pattern indicates their relative phases.

Phase adjustments are generally made with the system at rest (no input rotation). In order to provide sufficient output from the control amplifier for comparison with the input to the fixed voltage winding, it is desirable to physically hold the servomotor away from its correspondence position. The phase adjustment is then made so as to provide a 90-degree phase displacement.

When a new system is installed or components replaced, it is necessary to check for proper polarity relationships. Unless the fixed and controlled voltages have the proper polarity relationships, the servo will not have stability and the motor will run away. Likewise, if a rate generator (damping signal generator, fig. 10-9) is used in the servosystem, the output of the generator must have a polarity such that it will increase the system's stability rather than decrease it.

EFFECT AND ADJUSTMENT OF CONTROLLER GAIN

The overall gain of the system has a most important effect on the servomechanism onse characteristics and is one of the more ly adjustable parameters in electronic ocontrollers. Increasing the system gain ces the system velocity errors and those c errors resulting from restraining torques e servo load or misalinement in the system. ncrease in system gain also increases the em's natural frequency, and therefore its d of response to transient inputs. How- , excessive gain always decreases the rate hich oscillatory transients disappear, and inued increase in the system gain eventually uces instability. The optimum gain setting nds on the particular application for which servosystem is intended. The gain should ys be as high as is commensurate with em damping.

Vhen feedback networks are used, the relative s of these networks and the amplifier's ard gain must be adjusted in order to obtain num performance. If the gain settings for e two adjustments are not given in the ice instructions, they may be obtained ex- mentally by gradually adjusting first one hen the other.

ince the gain of the servo will be affected he phase of the various voltages, it is rable to check the phase adjustments before ng the gain adjustments. When small servo- rs are used, it is possible to measure the mic performance by checking the number vershoots. This may be done by causing otation to cease (example—stop the antenna ion of a radar installation), then manually ing the servomotor a certain number of es from correspondence, and then allowing snap back to its correspondence position. number of overshoots for a particular nt of servo displacement must be de- ned experimentally from equipment that ctioning properly. This may be used as a arison guide between the same types of ment. As a rule in aviation equipment, weight limitations, the servomotor has torque in excess of that required of it. se of this, whenever any additional load ded to the motor, the system is apt to e sluggish or intermittent. Oftentimes rvoamplifier is thought to be the cause above action when in reality it is due to crease in load. This increase may be by excessive mechanical friction due to n gear train or defective bearings and equently be detected by manually rotating rvomotor with the power removed. The amount of effort required to rotate the system that is not operating properly is compared with that required to rotate a system that is operating properly.

BALANCE ADJUSTMENT

Frequently servoamplifiers contain a balance adjustment to overcome any electrical unbalance that may occur in the amplifier. This unbalance is primarily caused by the unequal conduction of tubes. The adjustment is generally provided by connecting a potentiometer in the cathode circuits of the output tubes as shown by R21 in figure 10-7. This potentiometer is sometimes placed in the cathodes of the driver stage instead of the output stage. As the potentiometer is changed, the cathode bias will increase on one tube and decrease on the other, depending upon the direction of movement of the potentiometer arm. Thus by proper positioning of the arm, the tubes can be made to draw equal current.

When this adjustment is made, it is necessary to short out the input to the servoamplifier (this is possible in some equipment by rotating the gain adjustment to the zero position). With zero input to the amplifier, the balancing adjustment is rotated to the null or minimum voltage output from the servoamplifier. This indication is taken from a meter that is connected across the output winding or from a test jack.

APPLICATIONS OF TYPICAL SERVOMECHANISMS

The remainder of this chapter will be devoted to an explanation of the theory and operation of two different servomechanisms that are typical of airborne servosystems. The first explanation will explain the servomechanisms used to provide azimuth stabilization, and the second will explain a system for tilt stabilizing an airborne radar.

Azimuth Stabilization

Most azimuth stabilization systems are similar, and an understanding of one system will provide information that will be helpful in the comprehension of other systems.

An azimuth stabilization system stabilizes the indicator screen presentation, causing the display to remain rotationally fixed despite changes in the heading of the aircraft. By this means, a definite compass relationship is established for the indicator screen, and radar target echoes appear in proper position with respect to the top center of the screen, which represents magnetic north. The stability of the indicator presention also facilitates search during rough weather or moderate maneuvering of the aircraft.

In the following discussion of azimuth stabilization, an instrument called a fluxgate compass is used. The fluxgate compass employs most of the principles relative to so-called "earth field inductors," and later model compasses operate on those same principles.

Stabilization of the indicator screen pattern is accomplished by signal voltages controlled by the master indicator of the fluxgate compass (also called fluxvalve compass) in the aircraft. These signals are used to control the angle of the sweep trace on the screen in accordance with the instantaneous azimuth position of the scanner.

In order to explain the theory of operation of azimuth stabilization, it is necessary to analyze briefly one of the compass systems used. This is necessary since in an equipment that contains azimuth stabilization the compass that controls the stabilization is an intricate part of the system. The GYRO FLUXGATE COMPASS SYSTEM of the aircraft is a remote-indicating earth-indicator compass, which consists of a gyro-stabilized fluxgate transmitter, an amplifier, a master indicator, and one or more synchro remote-indicator repeaters. (NOTE: The term "gyro fluxgate" is a registered trade name of the Bendix Corporation.) The fluxgate element is stabilized in the horizontal plane by an electrically driven horizon gyro. The gyro head contains a rolling-ball type of erecting system, which maintains the gyro axis in the vertical plane by setting up a restoring force when the axis becomes displaced.

The transmitter portion contains the sensitive element of the system, the fluxgate unit, which consists of three equal legs forming a triangle; this unit is established and maintained in the horizontal plane by the action of the gyro. Each leg consists of two strips of a magnetic alloy used as a core upon which are wound a primary and a secondary coil. The primary coils are connected in series and are excited by an oscillator circuit in the amplifier. The secondary coils are delta connected, with leads tapped off at the points where the three coils join. These leads, and the single lead which supplies the excitation current, are brought out through hairsprings on the gimbal rings. The primary coil of each leg is wound in such a manner that when the leg is at right angles to the magnetic field of the earth the exciting alternating current produces opposing fluxes in each strip which neutralize each other and induce no voltage in the secondary. This exciting current saturates the core on the peak of each half cycle.

When the leg is parallel to the earth's magnetic field, the earth's flux tends to oppose the flux in one alloy strip and to aid the flux in the second strip. The partial cancellation of the flux in the first strip prevents its reaching saturation at the same time as the second strip, and its flux continues to change after the second strip has reached saturation. The flux difference thus set up induces a voltage in the secondary. When the current through the primary decreases to a point where the flux starts to drop below the point of saturation, a voltage in the opposite direction is induced in the secondary. This occurs because the flux in the first strip (in which partial cancellation exists) drops below the saturation point before the flux in the second strip, thus producing a flux change in the opposite direction. Since saturation occurs twice each cycle, and since secondary voltages are induced at the start and again at the finish of each period of saturation, the frequency of the induced voltage is double that of the primary voltage.

Three signal voltages, which generally are of three different magnitudes, are obtained from the fluxgate secondary coils, and are applied to the stator coils of a coupling synchro contained in the master indicator. The voltage induced in the rotor winding of this synchro is fed to the fluxgate amplifier, which develops sufficient power to operate a 2-phase induction motor which is also in the master indicator. The fluxgate amplifier includes an extremely stable oscillator that is used to furnish excitation power for the fluxgate and another oscillator which provides voltage for the continuously excited winding of the 2-phase induction motor in the master indicator. The excitation voltage applied to the induction motor is necessarily at equency of twice that of the fluxgate excita- voltage in order to equal the frequency of fluxgate output.

The 2-phase induction motor in the master- cator phase unit has its stator wound in drature (two windings at right angles to each r). The control winding is energized by the lified signal from the synchro rotor, and exciting winding receives its power from oscillator in the amplifier. When both dings of the induction motor are energized voltages having a phase difference of 90 rees, the motor rotates and drives the chro rotor through a gear train until the position is reached. When this occurs, voltage induced in the rotor drops to zero. output of the amplifier also becomes zero, since only the excitation winding of the ction motor is energized, the motor stops. position of the synchro rotor is therefore rmined by the position of the fluxgate with pect to the earth's magnetic field; con- ently, when the aircraft turns, changing azimuth relation of the fluxgate to the h's magnetic field, the synchro rotor and ched indicator pointer are turned by the ction motor through the same angle in the e direction. When the synchro rotor reaches null position, the master indicator shows magnetic heading of the aircraft. A trans- ing magnesyn, which is also turned by the ction motor, provides controlling voltages remote-indicating repeaters.

LYSIS OF AZIMUTH STABILIZATION

simplified schematic of the azimuth sta- ation section of the radar that will be used is analysis is shown in figure 10-11. The TER INDICATOR of the fluxgate compass em contains the transmitting synchro used this azimuth stabilization system. The of the transmitting synchro is mechanically led to the shaft that drives the pointer of naster indicator. As the aircraft changes eading, the rotor correspondingly changes ion at a one-to-one ratio. The stator of the mitting synchro is electrically coupled to contacts of relay K2101. This relay is gized by the operation of the bearing switch e control unit of the radar system. By ring to figure 10-11, it can be seen that 1 must be energized before the output of ransmitting synchro can be utilized in lization.

The ZERO SET SYNCHRO is utilized to zero set the PPI sweep position when the output of the transmitting synchro is not used, which is during relative bearing operation. The stabilization system will first be described as it relates to relative bearing operation; later it will be shown how azimuth stabilization is provided when the transmitting synchro of the aircraft compass system is connected to the azimuth followup synchro. When on relative bearing operation, the indicators are nonstabilized and the top of the indicator represents the heading of the aircraft; the targets are displayed with respect to the heading of the aircraft. The rotors of the zero set synchro and the transmitting synchro of the fluxgate compass are supplied excitation voltage from the same source. The zero set synchro is adjusted manually. Its positioning will be discussed later.

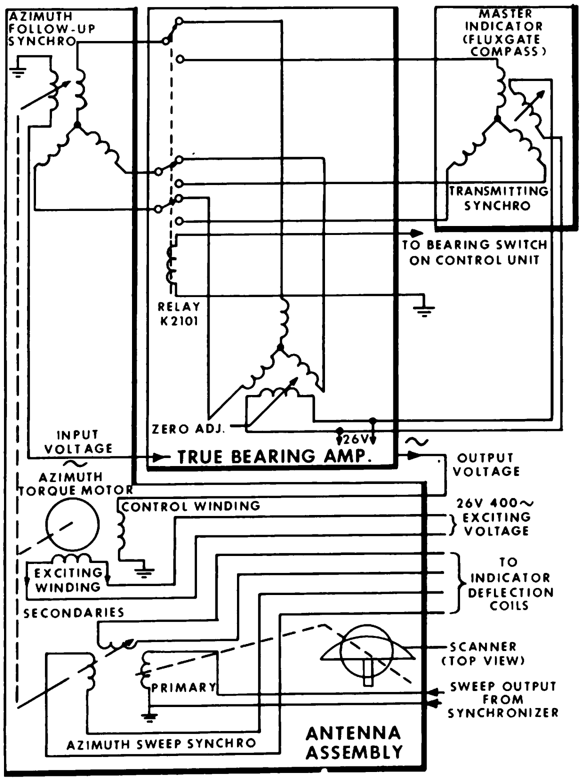


Figure 10-11.—Analysis of azimuth stabilization.

The stator of the AZIMUTH FOLLOWUP SYNCHRO is electrically coupled to either the stator of the transmitting synchro in the fluxgate compass, or the stator of the zero set synchro. The stator that is used for coupling depends upon the position of K2101. The rotor of the followup synchro is mechanically connected to the azimuth torque motor and the secondaries of the azimuth sweep synchro. The phase relationship between the rotor of the transmitting synchro or the zero set synchro determines the amplitude and polarity of the signal developed at the rotor of the followup synchro. When, for example, the rotors of the followup and the zero set synchros are 90 degrees displaced, as shown in figure 10-11, there will be no signal at the rotor of the followup synchro. If, however, the zero set rotor is turned 10 degrees, an error signal will be induced into the rotor of the azimuth followup synchro. The amplitude of the error signal produced will be dependent upon the amount of displacement between the rotors. The polarity or phase of the signal will depend upon the direction of displacement. The error signal is fed to the servoamplifier input of the true bearing amplifier which drives the azimuth torque motor.

The AZIMUTH TORQUE MOTOR is a 2-phase induction-type motor. The fixed voltage winding of this motor is connected to the same power source that supplies the rotors of the transmitting and the zero set synchros. The control winding is connected to the output of the true bearing amplifier. The amplitude and phase of the error signal applied to the control winding depend upon the amount and direction of displacement of either of the two exciting rotors (zero set or transmitter). The azimuth torque motor turns in a direction that is determined by the phase relationship of the voltages applied to these two windings. Since the torque motor is mechanically coupled to the azimuth followup synchro rotor, as it turns, it drives the followup rotor to a new null relationship with the rotor of the zero set synchro. As the rotors once again approach their 90-degree relationship, the amplitude of the error signal decreases, thus decreasing the amplitude of the voltage applied to the control winding of the torque motor. When the rotors of the zero set and the followup synchros are once again displaced by 90 degrees, there is no longer a signal applied to the control winding and the torque motor stops. As previously stated, the azimuth torque motor also turns the secondaries of the azimuth sweep synchros; thus, shifting the position of the azimuth sweep secondaries changes the position of the sweep on the indicators. For example, assume that the antenna is in a dead ahead position, with the sweep pointing to the top of the indicator. Then, by adjusting the zero set synchro to a setting of 10 degrees, which shifts the sweep secondaries by 10 degrees, the sweep position would move to 10 degrees.

The primary (rotor) of the azimuth sweep synchro is mechanically coupled to the antenna; thus, when the antenna rotates, the primary winding is also rotated. The primary winding is supplied with sweep voltages from the radar synchronizer. These voltages are induced into the secondary coils with a variation of phase and amplitude for each coil, depending upon its instantaneous angular relationship with the primary. The secondary voltages are applied to the vertical and horizontal coils of the PPI indicator. By means of these voltages, the angular deflection of the sweep trace on the PPI indicator is controlled in accordance with the instantaneous azimuth position of the radar antenna.

The example cited previously utilized the movement of the zero set synchro (manual adjustment) to move the secondaries of the azimuth sweep synchro and hence the PPI sweep. The same comparison may be made with the transmitting synchro. This synchro changes as the heading of the aircraft changes and this action coupled with the operation of the system just discussed is the analysis of azimuth stabilization.

COMPARISON OF THE TRUE AND RELATIVE BEARINGS

As already explained, changing the aircraft heading changes the positions of the sweep secondaries of the azimuth sweep synchro. This occurs on azimuth stabilization only and the change is automatic. On manual operation the only change that can be made is by varying the position of the zero set synchro. This is not stabilization, for it has no relationship to the movement of the aircraft. The zero set synchro is adjusted on manual or relative bearing operation. The antenna is set on zero degree with respect to the aircraft and the zero set synchro is adjusted until the sweep appears at the dead ahead position.

During relative bearing operation, with the azimuth indicating device at the top of the scope, and targets appearing thereon, a change in the bearing of the aircraft will result in a change of position of targets. This is an undesirable feature due to the fact that during the time the argets are shifting position they are hard to bserve on the indicators. See figure 10-12 (A) or a visual explanation of this condition. The op of the scope indicates the heading of the ircraft and all targets are displayed relative o this heading, thus on relative bearing operaion the top of the indicator indicates the heading f the aircraft. In other words, when the aircraft s heading north, the top of the scope is north. Vhen the aircraft is heading in any particular irection, the top of the scope is also that irection.

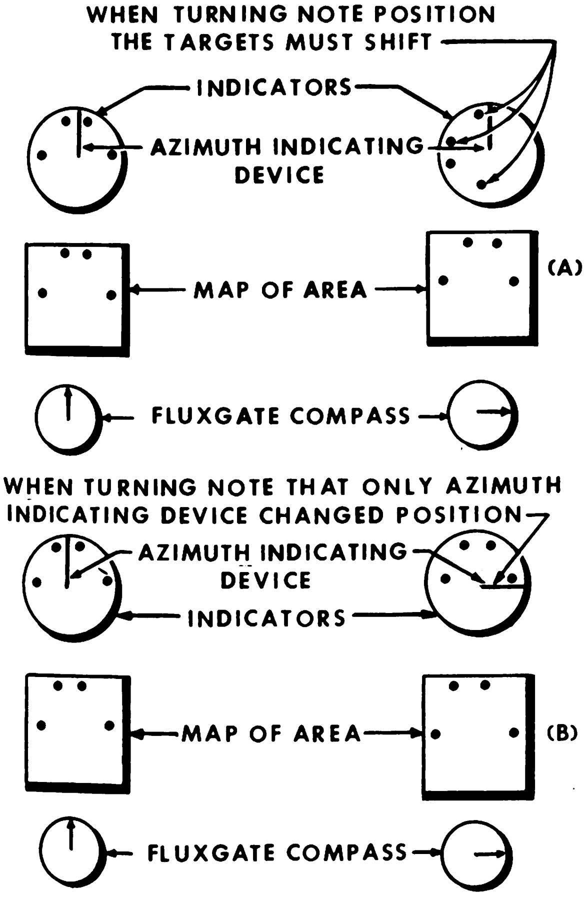

WHEN TURNING NOTE POSITION THE TARGETS MUST SHIFT
INDICATORS
AZIMUTH INDICATING DEVICE
MAP OF AREA
(A)
FLUXGATE COMPASS
WHEN TURNING NOTE THAT ONLY AZIMUTH INDICATING DEVICE CHANGED POSITION
AZIMUTH INDICATING DEVICE
INDICATORS
MAP OF AREA
(B)
FLUXGATE COMPASS

Figure 10-12.—Comparison of relative and true bearing operations.

The fluxgate compass controls the position the sweep on the indicators during true aring operation. As the fluxgate compass llows the aircraft's changes in heading, the ror signals coupled to the azimuth stabiliza- on system change the position of the sweep. ese changes in position occur at a one-to-one tio. Thus, if the aircraft heading changes a rtain number of degrees, the sweep secondaries will also change a like amount. Refer to figure 10-12 (B) for a comparative analysis of true bearing operation.

In this operation the azimuth indicating device, as on relative operation, represents the heading of the aircraft (providing the marker control on the radar control box is set to zero degree). The action of moving the sweep secondaries to correspond with changes in the heading of the aircraft causes the azimuth indicating device to shift. Hence, the azimuth indicating device will always indicate the heading of the aircraft and, when on true bearing operation, the top of the scope always indicates north (providing the marker control on the radar control box is set to zero degree). As the aircraft changes its heading, the targets remain in their position on the scope and only the azimuth indicator moves. Thus, the targets remain fixed, are always visible, and their relationship to the aircraft can be checked with the azimuth indicating device.

The top of the indicator represents magnetic north when the VARIATION is not set in, and true north when the variation has been set in. Variation is the angle between magnetic north and true north and differs at different points on the earth. The number of degrees of variation may be obtained from navigational charts. Some compass systems provide a means whereby variation may be added into the system; thus the compass will then indicate true north and a radar slaved to the compass will also indicate true north. In some aircraft installations that are equipped with a compass that does not provide this correction feature, a variation differential generator is included. This generator is connected between the transmitting synchro of the compass and the azimuth followup synchro in the radar. By adjusting this generator to the local variation it is possible to correct the radar to true north.

TRUE BEARING AMPLIFIER

(Refer to fig. 10-13.) The input to the true bearing (servo) amplifier is obtained from the rotor of the azimuth followup synchro. This error signal is applied across resistor R1 (sensitivity adjustment) which is paralleled by the primary of input transformer T1. The amplitude of this signal is determined by the amount of change in the aircraft heading, and the phase is determined by the direction of the

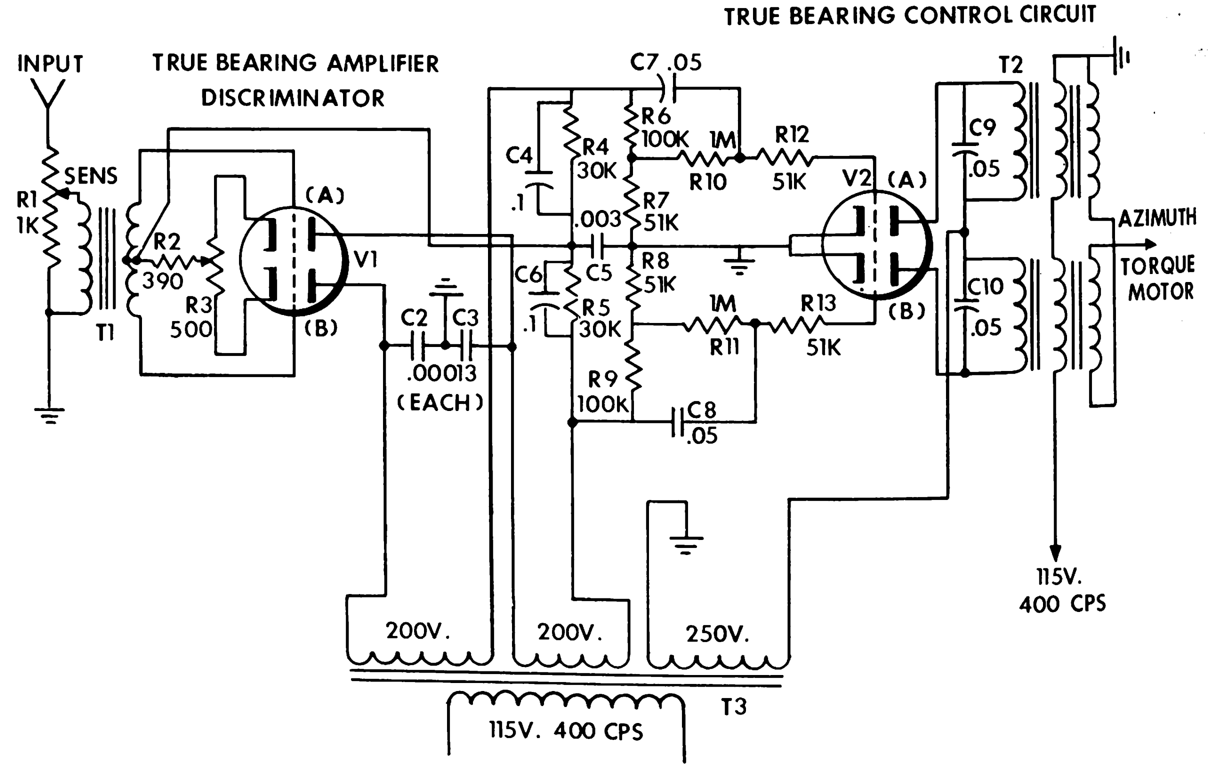


Figure 10-13.—AN/APS-33 true bearing amplifier.

change. The signal is transformer coupled to the grids of V1 which is the true bearing amplifier discriminator. The signals on the grids of V1, due to the transformer action, will always be 180 degrees out of phase. The plate voltages, due to the transformer connections, are always in phase. Thus, the grid that is in phase with the plate will determine which half of the duodiode conducts the hardest.

When the grid and plate of V1 (A) are in phase, its conduction charges the capacitors in the plate circuit. The plate current circuit is from the plate of V1 (A) through the source potential winding, plus to minus, then up through resistor R5. The current flowing through R5 develops a negative voltage at the bottom and charges capacitor C6. C6 in conjunction with C5 provides an a-c filter path to ground. The current flows from the junction point to resistors R4 and R5 back to the center tap of transformer T1. The path is then completed back to the cathode through the resistor R2 and the balance pot R3. During this same time, although V1 (B) has its grid negative and plate positive, it may still conduct a little. Its conduction path from the plate through the source potential causes current to flow through resistor R4 and develop a negative voltage at the top of R4. The negative voltage developed at the bottom of R5, however, far exceeds the negative voltage developed at the top of R4. Thus the voltage measurement from R5 is negative to positive. The voltage thus developed is coupled to the grids of the output control tubes.

The grid of V2 (B) is more negative than the grid of V2 (A). Any portion of the a-c signal not filtered out through capacitors C4, C5, and C6 is coupled through C7 and C8 to the grids of V2. In addition, the d-c signal developed across R6, R7, R8, and R9 is taken from the junction of the resistors and also applied to the grids. Hence, the grids contain both a-c and d-c components.

When the amplitude of the signal on either grid is too great, grid current is drawn; this limits the conduction of the tube. For example, when the amplitude of the signal on the grid of V2 (A) is excessively positive, grid current will flow through R10 and R12, thus adding to the bias on V2 (A).

The cathode of V2 is tied directly to ground. The voltages applied to the plates of V2 are in hase and conduction depends upon the grid ignals that are developed in the discriminator ircuit. In the case cited previously where 1 (A) conducted the hardest, the voltages eveloped in the output resistors made the grid V2 (B) most negative. Under these conditions, e current flowing through the plate windings the bottom control winding of the SATURABLE EACTOR assembly, T2, will be less than the rrent flowing through the upper winding. The rrent flowing through the control windings the saturable reactor assembly determines e amount of output signal developed.

The center winding or primary of the turable reactor assembly is excited by 115 lts a. c. The coupling from the primary to e output or secondary windings is controlled the conduction through the control windings. e control winding with the least current flow ows the greatest coupling from primary to condary. The output windings are wound in ries opposing. Capacitors C9 and C10 serve filter the a-c component and give a fairly nstant current flow through the control wind- s.

In the case cited previously, since V2 (B) is conducting the least, the saturation of the bottom section of T2 is less than that of the top section. Under these conditions the voltages developed in the bottom output winding far exceed those developed in the top winding. The polarity of the voltage taken from the output of the saturable assembly will be the same as that from the bottom winding. This voltage is applied to the control winding of the azimuth torque motor.

The rotor of the AZIMUTH TORQUE MOTOR is mechanically connected to the secondaries of the azimuth sweep synchro and the rotor of the azimuth followup synchro. The motor then drives the followup synchro rotor to a new null relationship with the rotor of the transmitting synchro, or zero set synchro, depending upon the position of K2101. One secondary winding of the AZIMUTH SWEEP SYNCHRO (resolver) is connected to the vertical winding of the deflection system, and the other is connected to the horizontal deflection winding.

See figure 10-14 for a descriptive analysis of changes in the azimuth stabilization system when the aircraft heading is changed. With the

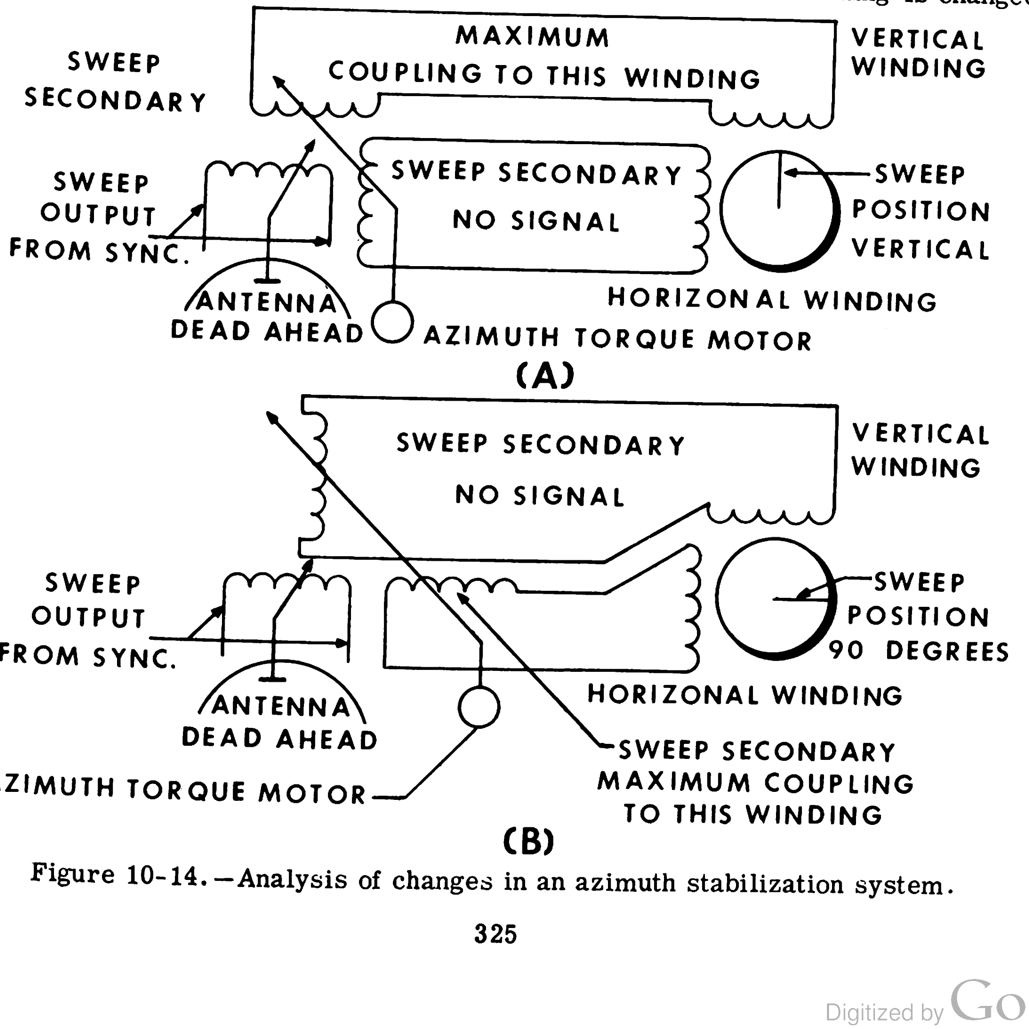


Figure 10-14.—Analysis of changes in an azimuth stabilization system.

antenna stopped in the dead ahead position, as shown in (A), an error signal is applied to the true bearing amplifier which causes the azimuth torque motor to turn. The sweep secondaries are then driven in a direction corresponding to the change in the transmitting synchro rotor, as shown in (B). When the aircraft changes its heading, the sweep position on the PPI scope will change accordingly.

Tilt Stabilization

The PURPOSE OF TILT STABILIZATION is to stabilize the tilt angle of the antenna of a radar system with respect to the earth. If the antenna is left unstabilized, when the aircraft changes its flight angle the antenna follows this change. If the antenna is dead ahead with respect to the aircraft and the plane begins a climb, the antenna will point up, thus losing targets. If, on the other hand, the antenna is pointing to port or starboard and the aircraft rolls to either side, the target returns will again be lost. If the antenna is stabilized with respect to the earth then the target loss, due to changes in the attitude of the aircraft, will be minimized. For example, assume that the antenna is pointing dead ahead in relation to the aircraft and the aircraft goes into a climb; if the antenna is stabilized, it will tilt down and maintain a constant angle with respect to the earth. The same holds true if the antenna is pointing to port or starboard and the aircraft is rolling; the antenna will tilt up or down, maintaining the constant reference with respect to the plane of the earth.

The stabilization range of the radar set which will be used for this explanation, is such that if the TILT control is set for 0, the beam is maintained at this angle for aircraft pitch or roll up to plus 30 degrees or minus 30 degrees. If the TILT control is set for other beam angles, these limits vary accordingly.

The tilt-stabilization system consists of a gyroscope, servoamplifier, resolver synchro, manual-tilt synchro, tilt-torque motor, damping-signal generator, and the followup synchro. (A diagram of this system is shown in figure 10-9). The gyroscope unit is separately mounted on the aircraft structure, and the resolver synchro and the servoamplifier are mounted on the antenna-assembly frame. The tilt-torque motor, damping-signal generator, and followup synchro are contained in the tilt-servo unit mounted on the rotary section of the antenna assembly. The manual-tilt synchro is mounted in the radar set control box.

Stabilization is effected by the use of two signals, the resolver-synchro signal and the manual-tilt synchro signal. Separate pitch and roll signals originating in the gyroscope unit are combined in the resolver synchro to produce the single resolver-synchro signal. The manual-tilt synchro signal originates in the followup synchro and provides the tilt-stabilization system with continuous information as to the tilt angle of the reflector. This signal passes through the manual-tilt synchro in the radar set control box where it is modified according to the setting of the TILT control. The resolver-synchro signal and the manual-tilt synchro signal, which differ in phase by 180 degrees, are combined at the input of the servoamplifier, and the amplifier resultant, or error signal, is used to control the tilt-torque-motor in correcting the tilt angle of the reflector.

GYROSCOPE UNIT

The gyroscope unit contains the gyro, with its drive motor, erecting mechanism, motor-driven caging and uncaging mechanism, and two synchros. The gyro, powered by a 26-volt, 400-cycle, 3-phase induction motor, establishes true vertical. The caging and uncaging mechanism is electrically operated, and is manually controlled by the GYRO switch on the radar set control. When caged, the gyro is clamped in an approximately vertical position with respect to its housing. CAGING OF THE GYRO prevents it from being damaged when the aircraft is engaged in maneuvers involving pitch or roll in excess of 60 degrees. The gyro develops a normal operating speed of 18,500 r.p.m.; when it is UNCAGED, the rolling-ball type ERECTING mechanism brings the gyro to true vertical and maintains it in this position. The gyro should be uncaged when in use and caged when the equipment is turned off. Although the GYRO switch may be in the UNCAGE position, the gyro is automatically caged when the POWER switch is turned off. After the equipment is turned on, the gyro remains caged during the warmup period of approximately three minutes, after which time the operation of the caging mechanism is dependent upon the position of the GYRO switch. The schematic diagram of the gyroscope unit is shown in figure 10-15.

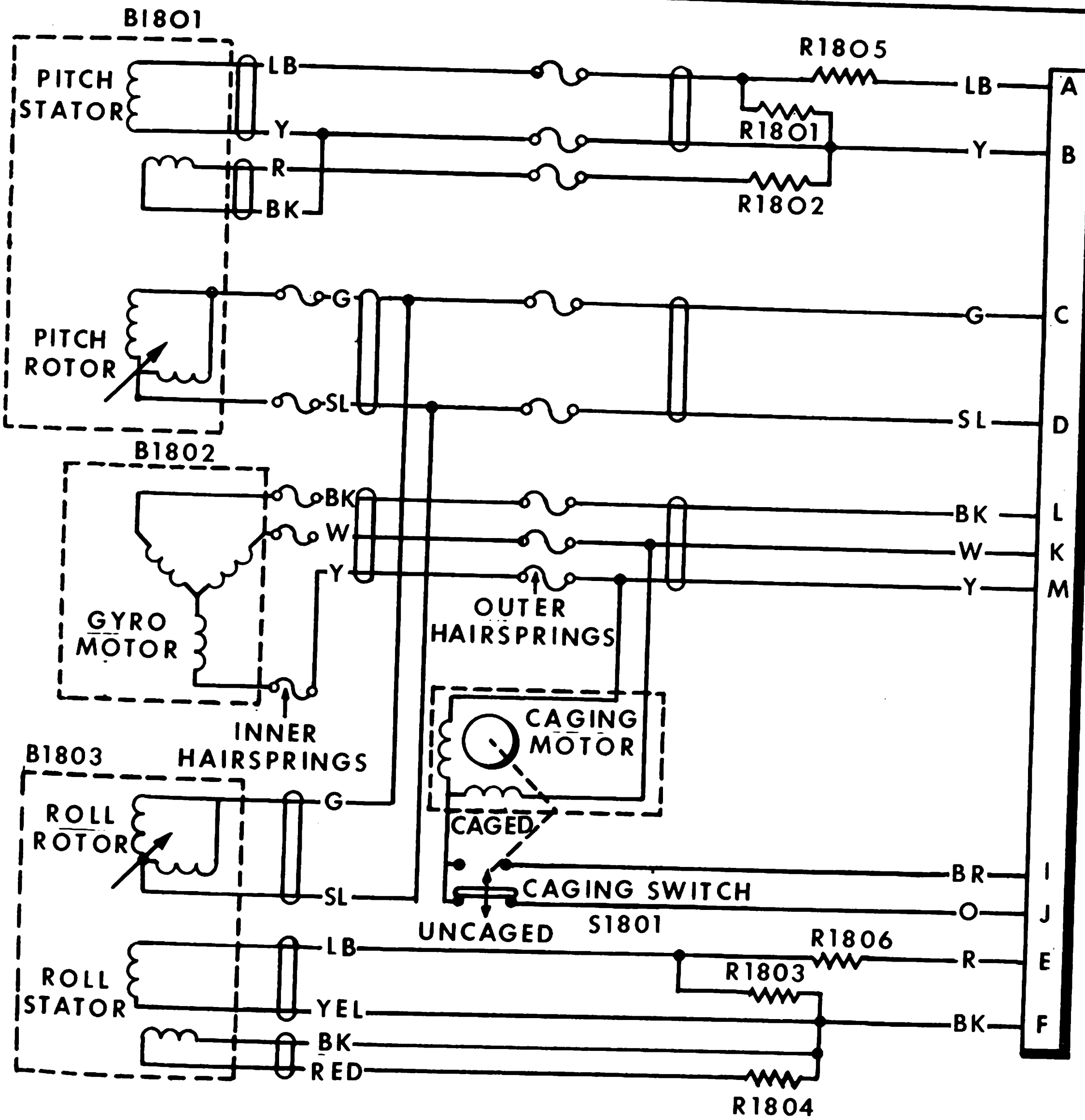


Figure 10-15.—Gyroscope unit.

The PITCH and ROLL synchros in the oscope unit deliver signals to the tilt-ilization system in the antenna assembly ccordance with the departure of the aircraft n level flight; these signals are used to ilize the tilt angle of the beam with respect he horizon. The rotor winding of each hro is excited by 26-volt, single-phase, cycle a.c. When either of the rotors is laced from the null point, single-phase ges are induced in the stators; the phase ionships and amplitudes of these voltages determined by the direction and degree of acement.

The stators of the two synchros are rigidly attached to the gyro, at right angles to each other. The rotor of the pitch synchro is mounted with its shaft horizontal, and at right angles to the line of flight of the aircraft. Since the rotor is fixed with respect to the aircraft, and the stator is fixed with respect to the gyro housing, an a-c pitch signal is developed when the rotor is displaced by the pitching of the aircraft.

The rotor of the roll synchro is also mounted with its shaft horizontal, but the shaft is parallel to the line of flight of the aircraft. Since the rotor is fixed with respect to the aircraft, and the stator is fixed with respect to the gyro, an a-c roll signal is developed when the rotor is displaced by the rolling of the aircraft. When the attitude of the aircraft combines both pitch and roll, pitch and roll signals are simultaneously produced by the gyroscope unit. These signals are fed to the resolver synchro in the antenna assembly. (See fig. 10-9.)

When displacement of the gyroscope synchros occurs, a torque is developed at the stator coils, which, if not compensated for, will cause the gyro to deviate from true vertical, thereby introducing errors into the reflector angle of stabilization. To counteract this effect, a balancing coil connected to a load resistor is mounted along with the stator of each synchro. When displacement of the rotor occurs, the magnetic field developed about the balancing coil causes a torque in the direction opposite to that already exerted on the stator, thus insuring stability of the gyro. The gyroscope unit is mounted on the aircraft structure and is provided with a reference base plate which is adjusted to a plane parallel to that of the antenna platform. The component is also provided with a sighting surface to permit alinement parallel to the lubber line of the aircraft.

RESOLVER SYNCHRO

Within the resolver synchro, the pitch and roll signals from the gyro are combined by induction in a rotor coil that is geared to the rotary head of the scanner, with which it rotates in a one-to-one ratio. Because of this mechanical coupling, the resultant resolver-synchro signal used in tilt stabilization experiences the proper variation throughout the scanning cycle to maintain the selected reflector tilt angle with respect to the aircraft for every azimuth position of the scanner. The net effect of tilt stabilization is to maintain a fixed predetermined angle of tilt between the reflector and the true horizontal, while the aircraft experiences the usual variations of normal flight.

The pitch and roll signals developed by the gyroscope unit are fed into the separate stator windings of the resolver synchro. These stator windings are mounted at right angles to each other. The orientation of the rotor is adjusted so that when the reflector is dead ahead, pitching of the aircraft causes maximum pitch signal to be induced in the rotor of the resolver synchro, and when the reflector is directed to extreme port or starboard, rolling of the aircraft causes maximum roll signal to be induced in the rotor of the resolver synchro. At intermediate positions of the reflector, combinations of both pitch and roll signals are induced in the rotor. One of these voltages may be either aiding or opposing the other, according to the attitude of the aircraft, with respect to the aximuth position of the reflector.

SERVOAMPLIFIER

The SERVOAMPLIFIER amplifies the error signal resulting from the combining of the manual-tilt synchro signal and the resolver-synchro signal, and controls the voltage to the tilt-torque motor, which corrects the tilt angle of the scanner.

The servoamplifier uses two resistance-coupled amplifiers, followed by a phase-discriminator stage and a pair of d-c amplifiers working into a saturable-reactor assembly. The output of the phase-discriminator stage, amplified by the d-c amplifiers, controls the a-c voltage that drives the tilt-torque motor. The direction of drive, which determines direction of tilt, is governed by the phase relationship between the exciting voltage and the control voltage of this motor; this relationship is, in turn, dependent upon the phase relationship between the motor-exciting voltage and the error voltage at the input of the servoamplifier.

The scanner is maintained at an angle of tilt with respect to the horizon. This angle is determined by the setting of the TILT control. This condition is achieved by combining the signal from the manual-tilt synchro with the one from the resolver synchro at the input of the servoamplifier. (See fig. 10-9.) The signal from the manual-tilt synchro is applied to one side of the ratio potentiometer, R1, and the signal from the resolver synchro is applied, through resistor R2, to the opposite terminal of the same potentiometer, whence they are combined in the servoamplifier. These two signals are 180 degrees out of phase, and when of equal amplitude they cancel each other. When this cancellation is complete, there is no control voltage for the tilt-torque motor, and consequently no tilt action is applied to the scanner.

When the aircraft rolls, the resolver-synchro signal is altered in amplitude, provided the scanner is not directed dead ahead or aft (at zero degree or 180 degrees azimuth). When the aircraft pitches, the resolver-synchro signal is altered in amplitude, provided the scanner is not directed at 90 or 270 degrees relative azimuth. As a result, the resolver-synchro signal and the manual-tilt-synchro signal no longer cancel, and an error signal is developed at the input of the servoamplifier. After amplification, this error signal is applied to a phase discriminator, which determines from the phase of the signal whether the reflector must be tilted up or down in order to correct for the roll, pitch, or combination of the two that has just caused the error signal. The output of the phase discriminator drives the proper tilt-servocontrol tube, which then applies the control voltage to the tilt-torque motor by means of a saturable reactor. As the tilt-torque motor corrects the scanner tilt angle, the rotor of the followup synchro, which is coupled to the tilt-torque motor, is turned in such a direction that the manual-tilt synchro signal changes in amplitude to compensate for the change in the resolver-synchro signal. When these two signals cancel again, the necessary correction to the reflector tilt angle has been accomplished, and he tilt-torque motor stops.

The ratio potentiometer, R1, balances the ignals from the manual-tilt synchro and the esolver synchro to compensate for possible leviation from the true horizontal of the nounting plane of the gyroscope unit.

This servoamplifier functions similarly to ne one discussed under "Azimuth Stabilization" n this chapter, in that the error voltage controls ne saturable reactor which provides the variable oltage for the control winding of the tilt-orque motor. (See fig. 10-9.)

In this tilt-stabilization system one winding f the TILT-TORQUE MOTOR is continuously xcited by 115 volts a.c. The other winding, sed to control the starting and operation of e motor, is supplied from the saturable eactors with a-c voltage developed whenever error signal is amplified by the servo-nplifier. The motor torque is obtained by oviding approximately 90 degrees phase dif-rence between the control voltage and the citation voltage, by means of capacitor C10 ich is shunted across the control winding. e speed of the motor is dependent upon the plitude of the control voltage, which in turn dependent upon the action of the TILT control, t stabilization, and damping.

MANUAL-TILT CONTROL

The scanner tilt angle is controlled by the tilt synchro in the radar set control and is adjusted by means of the TILT control. The tilt synchro is connected with the followup synchro in the tilt-servo unit. Supplied with a steady a-c voltage, this synchro circuit develops the manual-tilt-synchro signal in its rotor to control the tilt angle of the beam with respect to the angle of tilt stabilization (approximate horizon). The signal from the manual-tilt synchro is fed to the input of the servoamplifier, where it is combined with the resolver-synchro signal. Control of the scanner tilt angle is therefore dependent upon the resultant sum of these two voltages, and is accomplished through the system used for tilt stabilization, as just described. If the resolver-synchro signal is switched off by means of the STAB-UNSTAB switch S2 on the servoamplifier, the beam-tilt angle is then established only with respect to the aircraft.

FOLLOWUP SYNCHRO

The followup synchro and the manual-tilt synchro develop the manual-tilt-synchro signal. The followup synchro is located in the tilt-servo unit of the antenna assembly. The rotor of this synchro is mechanically coupled to the tilt mechanism so that the rotor movement occurs in synchronism with the tilting of the scanner. The stator windings of the followup synchro are connected to the stator windings of the manual-tilt synchro in the radar control unit. The rotor of the followup synchro is supplied with 26-volt, 400-cycle, single-phase voltage. Voltages of unequal amplitude are induced in the stator windings (fig. 10-9). These voltages are reproduced in the stator windings of the manual-tilt synchro in the radar set control. When the rotor position of the manual-tilt synchro is such that its signal cancels the resolver-synchro signal and produces a null at the input of the servoamplifier, no control voltage is developed for the tilt-torque motor and the scanner tilt angle is not changed. When the rotor is displaced from this position in either direction by resetting the TILT control for a new beam tilt, one signal becomes larger than the other, cancellation is no longer complete, and therefore an error signal is developed which causes the servoamplifier to develop a control voltage for the tilt-torque motor. As the motor drives the scanner to the required tilt angle, a mechanical coupling from the motor turns the rotor of the followup synchro. When the manual-tilt synchro again cancels the resolver-synchro signal at the input of the servoamplifier, the tilt-torque motor stops, the beam-tilt angle thus obtained is determined with respect to the horizontal.

The function of the DAMPING-SIGNAL GENERATOR that is used with this system of tilt stabilization has already been explained in this chapter in connection with Antihunt Devices. It is of interest to note that the hunting of the scanner in this equipment is held to a maximum of plus or minus one-half degree of tilt about the angle of stabilization. This, as you can easily understand, is a very close tolerance of error and thus, hunting is adequately eliminated.

QUIZ

1. Which of the following statements best describes a servomechanism system?
   a. A system for transmission of angular information
   b. A power amplifier to supply a split-phase induction motor
   c. An error indicating system to show the displacement of one shaft from another
   d. A system that transmits angular information with an amplification of power

2. The component of the servoamplifier in figure 10-4 that transforms the a-c error signal into a d-c signal is the
   a. sense detector
   b. a-c amplifier
   c. d-c amplifier
   d. modifying network

3. With reference to figure 10-7, when the error voltage at terminal 3 of T1 is of the same polarity as the reference voltage at terminal 3 of T4,
   a. V4-A or V3-B will conduct and the output at terminal 6 of T2 will be in phase with the reference voltage
   b. V4-B or V3-A will conduct and the output at terminal 6 of T2 will be 180 degrees out of phase with the reference voltage
   c. V4-A or V3-B will conduct and the output at terminal 6 of T2 will be 180 degrees out of phase with the reference voltage
   d. V4-B or V3-A will conduct and the output at terminal 6 of T2 will be in phase with the reference voltage

4. The antenna hunts up and down continuously. (See fig. 10-9.) To correct this condition adjust
   a. R1 up
   b. R1 down
   c. S1 to the right
   d. S1 to the left

5. A block diagram of servo controller components would always include a/an
   a. modulating device
   b. vacuum tube device
   c. phase sensitive device
   d. electromechanical generating device

6. The main disadvantage of using a multiple-speed error detector is
   a. the need of an additional synchro system and switching circuit
   b. that they tend to be inaccurate
   c. the possibility of locking-in on an incorrect position
   d. that the mechanical complexity is impractical

7. The plates of the diodes (fig. 10-5) are fed
   a. push-pull by the reference voltage and push-pull by the error voltage
   b. push-push by the reference voltage and push-pull by the error voltage
   c. push-push by the reference voltage and push-push by the error voltage
   d. push-pull by the reference voltage and push-push by the error voltage

8. The purpose of feedback as used in a servomechanism (fig. 10-8) is to
   a. cancel hunting
   b. position the control transformer for zero error signal
   c. turn control transformer stators
   d. cancel error signals

9. Which one of the following antihunt devices utilizes a resonant circuit in its operation?
   a. The limiter type
   b. The inertia damper type
   c. The damping signal
   d. The derivative type

In a servomechanism system, the controller is the
a. synchro transmitter
b. error indicator
c. servoamplifier
d. feedback device

To prevent overshoot in a servomechanism, without sacrificing accuracy and speed of response, it is a good idea to
a. apply some additional friction to the output shaft
b. reduce the gain of the servoamplifier
c. utilize a damping signal generator
d. utilize an inertia damper on the output shaft

In figure 10-5, the speed of rotation of the load is determined by the
a. relative polarities of the error and reference voltages
b. magnitude of the reference voltage
c. phase of error voltage
d. d-c voltage charge on C1 or C2

In figure 10-5, the direction of load rotation is determined by the
a. relative polarities of the error and reference voltages
b. magnitude of the reference voltage
c. phase of the error voltage
d. magnitude of the error voltage

The purpose of azimuth stabilization is to
a. facilitate determination of relative bearing of targets
b. facilitate low altitude bombing
c. allow targets to change position as your heading is changed
d. maintain the top of the indicator at true or magnetic north

What would be the output from the true bearing amplifier circuit (fig. 10-13) if R1 sense pot) was moved all the way down?
a. Zero
b. Constant phase and amplitude
c. Constant phase with varying amplitude
d. Varying phase with constant amplitude

The error detector is usually a
a. differential generator
b. synchro control transformer
c. synchro transmitter
d. magnesyn

17. The balance control in a servomechanism is adjusted
a. for the fastest response without hunting
b. for a maximum output when no error signal is applied
c. to compensate for variations in line voltage
d. for zero output when no error signal is applied

18. With no error voltage applied to T2 (fig. 10-6), the exciter field flux would be
a. in phase with the reference voltage
b. maximum in intensity
c. minimum in intensity
d. varying in intensity

19. When a two-phase servomotor is used to position a load, the voltages supplying the two field windings should be
a. 180 degrees out of phase
b. in any phase relationship
c. in phase
d. 90 degrees out of phase

20. The purpose of the zero set synchro (fig. 10-11) is to
a. electrically zero the synchro system
b. aline the sweep on the indicator with the antenna on relative bearing operation
c. correct for compass error on true bearing operation
d. aline the sweep on the indicator with the antenna on true bearing operation

21. The component of the tilt stabilization system (fig. 10-9), which interprets the amount of correction to be applied in order to correct the antenna's position in a vertical plane to coincide with its position in the azimuth plane, is the
a. resolver synchro
b. followup synchro
c. manual tilt synchro
d. servoamplifier

22. What is the purpose of tilt stabilization?
a. To keep the antenna pointing dead ahead of the aircraft
b. To prevent the antenna from following changes in flight angle
c. To allow the antenna to follow changes in flight angle
d. To prevent loss of targets when maneuvering by stabilizing the aircraft with respect to the earth's surface

23. Inertia dampers are used on
a. synchro transmitters
b. synchro control transformers
c. control transformers
d. differential generators

CHAPTER 11

TRANSISTOR CIRCUITRY

TRANSISTOR PRINCIPLES

The material presented in this chapter supplements that in the training course, *AT 3 & 2*, NavPers 10317-A. The theories of matter structure and transistors presented here utilize different approaches and deeper coverage than is found in *AT 3 & 2*, and will give a more detailed understanding of those subjects. The objective of this chapter is to acquaint you as thoroughly with transistors and their several uses as you are now acquainted with vacuum tubes, and to enable you to think of them with the same ease.

Conduction Through Semiconductors

A semiconductor is a material having a conductivity lower than that of a conductor but higher than that of an insulator. For example, a germanium crystal in its purest state acts as an insulator, but when a small amount of impurity such as arsenic is added to it, the crystal becomes a satisfactory conductor.

The semiconductors used in transistors include germanium and silicon. A new concept is needed to understand the somewhat unexpected performance of these materials.

Atomic Structure

A brief review of the atomic structure of crystalline matter will be helpful in understanding transistor action.

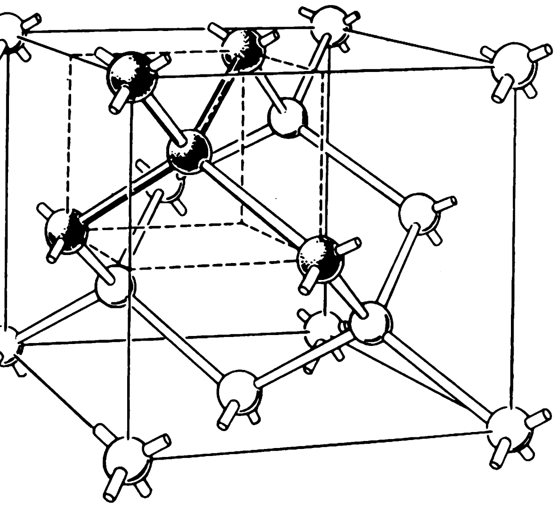
An atom (in its normal state) consists of a positive nucleus containing a fixed number of protons surrounded by an equal number of electrons in various orbital levels. Each orbit can contain not more than a fixed number of electrons. When an orbit contains this fixed maximum number of electrons, it is said to be complete. In atoms, the inner orbits are complete; whereas, the outer orbits may be incomplete. The innermost (complete) orbits, together with the core, form a stable "ionic core" with a net positive charge. The core can be considered completely inactive as far as chemical reactions and electrical phenomena are concerned. Only the outermost ring of electrons determines the chemical and electrical characteristics of the substance.

Valence Bonds

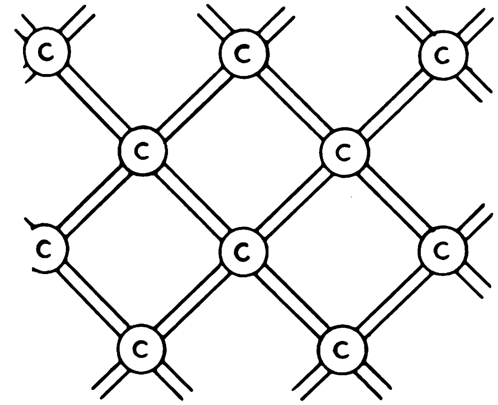
Electrons in the outer orbits of atoms form VALENCE BONDS between adjacent atoms. These bonds, which hold the atoms rigidly in place in solid crystalline substances, are stable for certain given numbers of electrons in the outermost ring. For example, the bond is especially stable when it contains precisely two electrons. The bond is weakened when one electron is removed; it is not strengthened much when a third electron is added.

The elements carbon, silicon, and germanium, have the common property of being tetravalent; that is, only four of their outer electrons are able to enter into chemical reactions. The four valence electrons form bonds with four electrons from adjacent atoms to form a crystal structure known as the DIAMOND LATTICE, (crystalline form of carbon, silicon, and germanium). The atoms are arranged in a definite pattern as indicated in figure 11-1. The position of an atom is known as a lattice site.

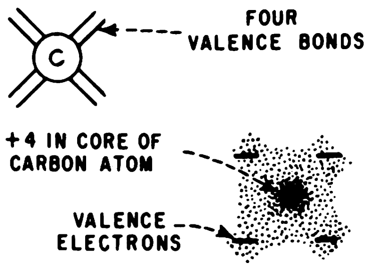
The three-dimensional diamond lattice in figure 11-1 is redrawn in two-dimensional form in figure 11-2. Figure 11-2 (A) illustrates how each bond between adjacent atoms is shared, resulting in a stable covalent bond. Therefore every electron is tightly bound and unable to leave the "lattice" structure. This condition explains why the diamond is a good insulator.



igure 11-1.—Three-dimensional diamond lattice.



(A) TWO DIMENSIONAL



(B) NEUTRAL ATOM

Figure 11-2.—Simplified diamond lattice.

11-2(B) illustrates the fact that each with its share of valence-bond electrons, trically neutral.

Conductivity can be produced in a diamond in several ways, all of which involve destroying the perfection of the valence-bond structure. One way is to bombard the diamond with high-energy radiation, which breaks the bonds and causes electrons to be ejected from them. The bonds in silicon and germanium are weaker than diamond bonds and can be broken by heating. The increase in thermal agitation causes the bonds to break.

If a sample of germanium or silicon with broken bonds is subjected to a voltage, two kinds of current will flow. The ejected electrons move through the crystal from the negative terminal to the positive terminal, thus constituting ordinary conduction (electron) current. The second current (hole current), however, results from the motion of electrons from one valence bond breaking away to fill up the hole caused by the absence of an electron from an adjacent bond. Thus, holes seem to move in a direction opposite to that of electron flow. Because the hole is a region of net positive charge, the apparent motion is like the flow of positively charged particles.

These two currents are called electron current and hole current. If a suitable "impurity" is added to the semiconductor, the resulting mixture can be made to have either (1) an excess of electrons, thus causing more electron current, or (2) an excess of holes, thus causing more hole current.

Impurity Donors and Acceptors

If arsenic is mixed with a semiconductor such as silicon, the application of a voltage across the resultant crystal will produce more electron current than hole current. This action results from the fact that each atom of arsenic with five valence-bond electrons, when introduced into silicon as a low-fraction impurity, occupies the position of one atom of silicon at a lattice site and forms four co-valent bonds with the surrounding silicon atoms, utilizing four of its valence-bond electrons. The extra electron, however, cannot fit into any of the bonds and is free to move inside the crystal. A semiconductor with excess electrons such as silicon with arsenic is called an N-type substance because the current carriers are negative electrons. Arsenic, phosphorous, antimony, and other impurities that make N-type semiconductors are called DONORS.

Current flow through an N-type material is indicated in figure 11-3. The current flow comprises the movement of excess electrons along corridors bound by normally bonded atoms at the lattice sites. No electrons are missing from these atoms.

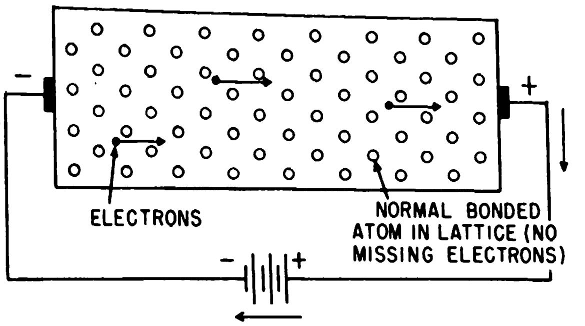


Figure 11-3.—Conduction by electrons in N material.

If an impurity such as boron is added to a semiconductor, the resulting mixture has an excess of holes. This condition results from the fact that each atom of boron with three valence-bond electrons, when introduced as a low-fraction impurity, occupies the position of one atom of silicon at a lattice site. In this position, it forms four co-valent bonds with the surrounding silicon atoms, thereby using all three of its valence-bond electrons and robbing an electron from a neighboring atom of silicon. The net positive charge remaining when an electron is removed from a silicon atom at a lattice site is equivalent to a hole created by the missing electron. The hole can be filled by an electron from an adjacent bond; but this again leaves a hole where that electron came from. Thus when a voltage is applied, the holes appear to move and to contribute to the conductivity of the semiconductor. Semiconductors with an excess of holes are called P-type semiconductors. Aluminum, gallium, indium, boron, and other impurities that make P-type semiconductors are called ACCEPTORS.

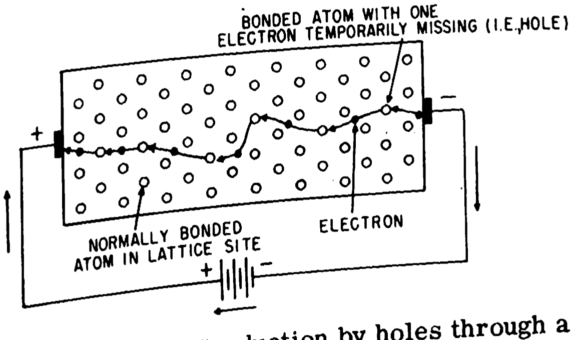

BONDED ATOM WITH ONE ELECTRON TEMPORARILY MISSING (I.E. HOLE)
+
−
NORMALLY BONDED ATOM IN LATTICE SITE
ELECTRON
+
−

Figure 11-4.—Conduction by holes through a P-type semiconductor.

Conduction by holes through a P-type semiconductor is indicated in figure 11-4. The holes are formed at the positive terminal by an electron deficiency in the lattice-site atoms. The electron deficiency progresses toward the negative terminal.

Point-Contact Transistor

The point contact between a metal and a semiconductor is commonly used as a rectifier, as in crystal detectors. Rectification means that the contact resistance is high for one direction of current flow and low for the other direction. The direction of the low-resistance path is that in which electrons flow from the semiconductor to the metal.

Figure 11-5 illustrates the arrangement of a point-contact transistor. The base is a small flat square of N-type germanium crystal about 0.02 in. thick and about 0.05 in. long. Point contacts are established by two phosphor bronze wires, each of which has a cross-sectional area of about 25 cir mil (wire size No. 36). The point contacts are spaced about 0.002 in. apart.

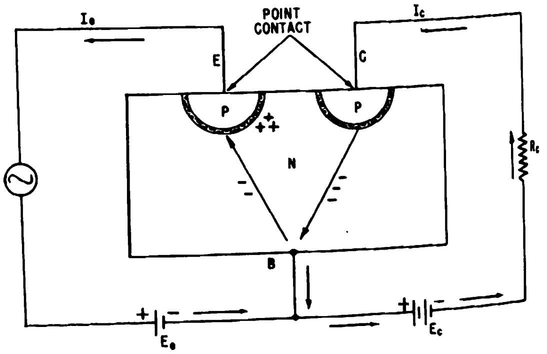


Figure 11-5.—Point-contact transistor.

The contact pressure between the point contact (cat's whisker) and the germanium, the heating of the points by currents introduced into the transistor, and the high-intensity electric field about the points all contribute to the production of small areas of P material in the immediate vicinity of the points. The shaded areas en the P material and the N material repre- arrier layers, which in the absence of ex- voltage, prevent the holes in the P ma- from moving into the N material or the ons in the N material from moving into material.

N materials, the impurity atoms have a net ve charge. In P materials, the impurity have a net negative charge. In both ma- s, the impurity atoms occupy lattice sites rly occupied by the semiconductor atoms pure state. Donor materials donate (give ectrons, leaving their atoms with a net ve charge. Acceptor materials accept (take ctrons, thereby causing their atoms to ac- a net negative charge. In the conduction ss, the current flow is the movement of holes or electrons along the corridors by the atoms at the lattice sites.

NCTION

the PN junction illustrated in figure 11-6 ne P material is shown at the left and the erial is shown at the right. The P ma- contains acceptor impurity atoms. These are represented by negative signs en- in circles. As mentioned before, these take on electrons from the pure crystal, g holes as the current carriers. The holes presented in the P material as positive s. The N material contains donor atoms ve up electrons when they become a part crystal lattice. The donor atoms are ented as positive charges enclosed in . The free electrons in the N material epresented as interspersed negative s between the donor atoms.

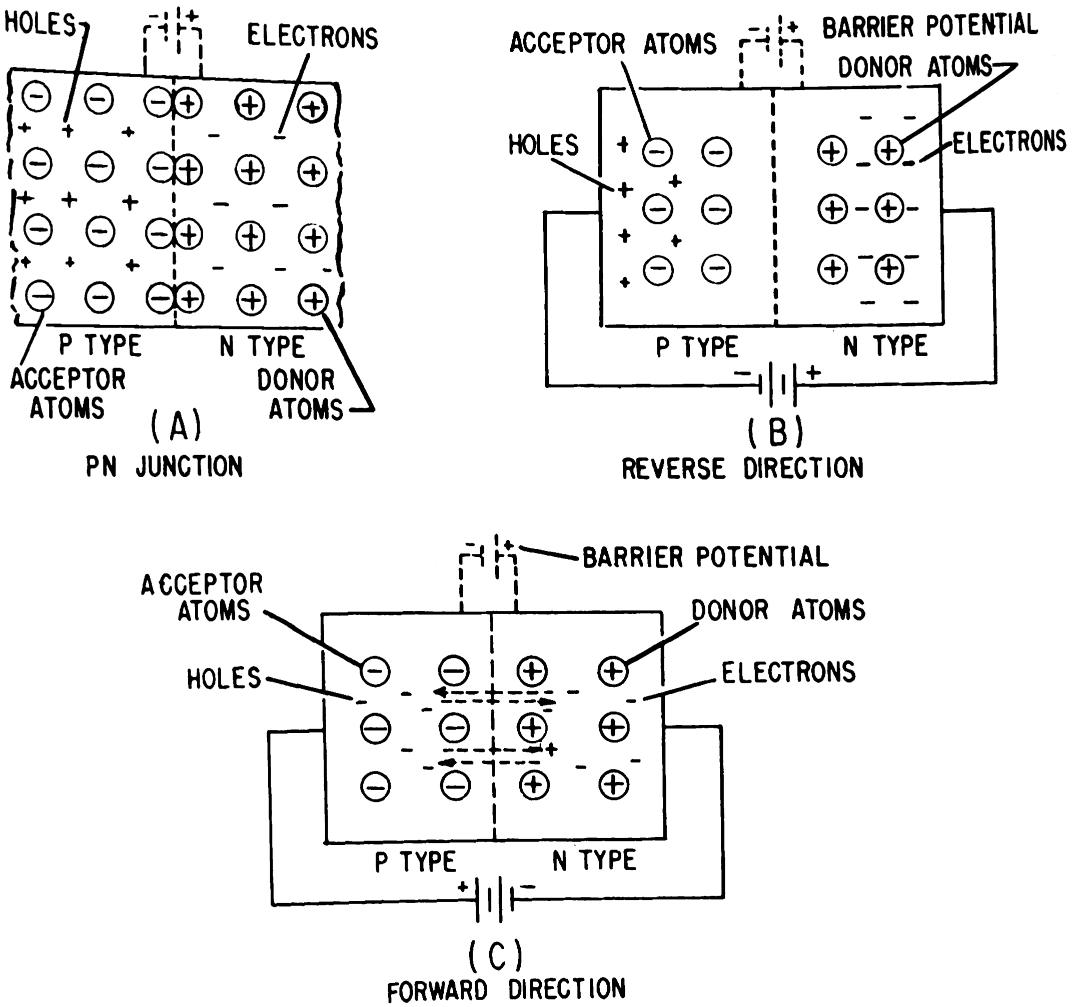
ormal temperature, the positive holes in naterial do not move across the junction I material because of the repelling effect arrier layer of positively charged donor n the N material. Similarly, electrons material do not move across the junction material because of the repelling effect barrier layer of negatively charged ac- toms in the P material.

all barrier voltage is developed across unction. This voltage is represented by ed batteries in figure 11-6 and is of the a few tenths of a volt. If an external is connected across the PN junction with tive terminal connected to the same ma- the negative side of the barrier potential and the positive terminal connected to the same side as the positive side of the barrier potential (fig. 11-6, (B)), the barrier voltage will be reinforced. This connection is in the direction of high resistance to current flow. The effect of the barrier potential is referred to as a "potential hill." In the P-type material, the holes are attracted away from the junction toward the negative terminal of the battery. Similarly in the N-type material, electrons are attracted toward the positive terminal of the battery. The counter attraction of the charges on the immovable impurity atoms balances this action and stops the flow. The region close to the junction has all of its conduction electrons and holes removed, thereby becoming effectively an insulator. The barrier is a temporary insulator because of the absence of current carriers.

If the external battery connections are reversed (fig. 11-6 (C)), the potential hill is overcome, or lowered. This connection is in the direction of low resistance. Electrons from the N-type material will now move across the junction into the P-type material; holes from the P-type material will now move across the junction into the N-type material. In both cases these holes and electrons will combine, with each electron filling a corresponding hole. Meanwhile new holes are created at the positive terminal, and more electrons are injected at the negative terminal as a result of the battery action. To maintain the flow, only a few tenths of a volt is required across the junction in addition to the resistance drop in the forward direction across the P- and N-type material.

In the point-contact transistors of figure 11-5, the emitter, E, is biased in the forward direction, or the direction of low resistance. The collector, C, is biased in the reverse-current direction, or the direction of high resistance. In transistors, the emitter is always biased in the forward, or low-resistance direction; whereas, the collector is always biased in the reverse, or high-resistance, direction.

The magnitudes of the voltages applied to the transistor are small for both the forward and the reverse connections. The bias voltage and the signal voltages are small in the emitter circuit in order to limit the current flow in the forward direction to a value that will not cause excessive heating of the transistor. In order to prevent voltage breakdown within the transistor, the voltage applied to the collector in the inverse direction (fig. 11-6 (B)) is also limited to a relatively small value.



(A)
PN JUNCTION

(B)
REVERSE DIRECTION

(C)
FORWARD DIRECTION

Figure 11-6.—PN junction.

The cat's whisker is used to develop a high-intensity electric field, in the vicinity of the emitter without requiring the application of a high external voltage source. This high-intensity electric field overcomes the barrier potential between the P material and the N material. This action allows electrons to move from the N material across the PN junction to the P material, and, at the same time, allows holes to move from the P material across the PN junction to the N material. In the external circuit of the emitter, electrons flow from the emitter contact, E, counterclockwise around the circuit, returning to the transistor N material at the base, B, and completing the circuit to the PN junction in the vicinity of E.

HOLE INJECTION

The bias battery for the emitter circuit of the transistor (fig. 11-5) overcomes the barrier potential at the PN junction around the emitter point contact so that holes in the P material can move across the junction and into the N material at the same time electrons move from the N region across the junction and into the P region. In the collector circuit the battery E_C, biases the transistor in the reverse, or high-resistance, direction, thereby reinforcing the barrier potential existing across the PN junction around the collector, C.

The movement of holes from the emitter region into the collector region is known as

OLE INJECTION. As holes are injected into ne collector region of the N material, they xert an attractive force on the electrons, asisting them across the PN barrier around the ollector, increasing the collector current. The ffect is the same as though the barrier potenal were neutralized so that more electrons an flow across the barrier. The action is nalogous to that of a space charge or cloud of ositive ions in a conducting gas tube. The ositive ions neutralize a portion of the negave space charge around the cathode, thereby icreasing plate current. In the transistor, the oles attract additional electrons across the ollector PN barrier and increase the flow of ollector current.

URRENT GAIN

The ratio of change in collector current to nange in emitter current for a constant colctor voltage is the current gain (α) of the ansistor. For the point-contact transistor, is greater than 1.

If an a-c signal is introduced in series with ne d-c bias in the emitter, the resulting transr of holes from emitter to collector will vary magnitude with the signal. Thus, the collector irrent will vary in accordance with the input gnal.

A point-contact transistor has charactertics that are analogous to those of an electron be. Figure 11-7 represents a point-contact ansistor circuit, and a curve of collector rrent, I_C, versus the collector voltage, E_C, r a constant emitter current, I_e. At low values of E_C, the steep slope of the curve from (0 to A) indicates a low-effective resistance of the collector circuit.

The low-effective resistance is the result of the diffusion of holes from the emitter into the N material around the collector barrier. As mentioned before, the holes neutralize the barrier potential so that more electrons can flow across the barrier.

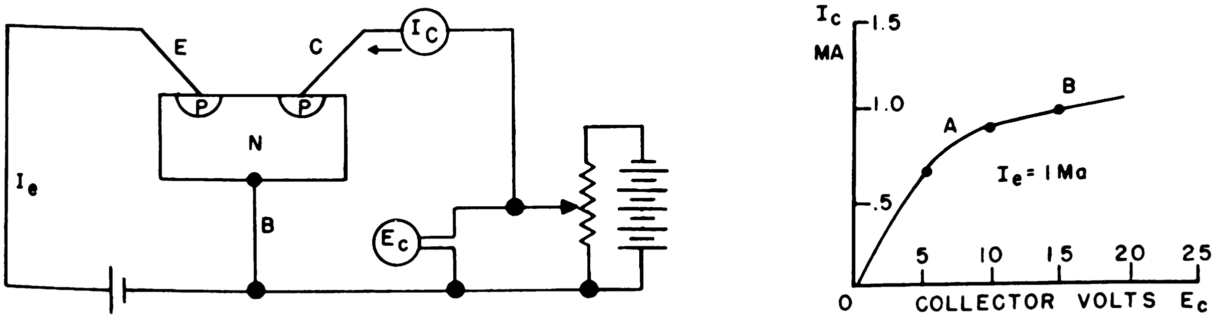
The change in slope at A indicates a change in the resistance of the collector-to-base circuit, and the small slope from A to B represents a relatively high collector-to-base resistance. The point-contact transistor is normally operated in the B region.

Collector current consists of the holes from the forward-biased emitter that diffuse through the base and are attracted to the reverse-biased collector. A few of the holes from the emitter do not reach the collector due to recombination with electrons within the base. Current also flows from the collector to the base which varies at the signal rate. This results in the current gain of the point-contact transistor being greater than unity.

RESISTANCE GAIN

The resistance of the emitter and collector circuits depends on the circuit connections. The resistance gain of a point-contact transistor having an emitter circuit resistance, r_e, of 300 ohms and a collector circuit resistance, r_c, of 15,000 ohms will be

$$\frac{r_c}{r_e} = \frac{15{,}000}{300} = 50.$$



(A)
CIRCUIT

(B)
I_C VS E_C CURVE

Figure 11-7.—Point-contact transistor characteristics.

VOLTAGE GAIN

If the current gain, α, of this transistor is

$$\frac{\Delta I_c}{\Delta I_e} = \frac{3 \text{ ma}}{1.5 \text{ ma}} = 2,$$

the voltage gain will be

$$\frac{\Delta I_c r_c}{\Delta I_e r_e} = \frac{3 \times 15,000}{1.5 \times 300} = 100.$$

POWER GAIN

The power gain in this example will be

$$\frac{\Delta I_c{}^2 r_c}{\Delta I_e{}^2 r_e} = \frac{3^2 \times 15,000}{1.5^2 \times 300} = 200$$

Thus, the power and voltage gain of the point-contact transistor in these examples is due principally to the relatively high resistance gain.

HOLE LIFE

The movement of holes from the emitter to the collector is by way of the N material in the intervening space between the two P regions. This movement is accompanied by a certain amount of recombination of electrons with holes, and hence a reduction in the number of holes arriving at the PN collector barrier. Because of this recombination, the length of life of the holes injected into the N material is of the order of a few thousand microseconds.

HOLE AND ELECTRON SPEED

The speed of response of holes in semiconductors to a signal voltage is considerably less than that of electrons in metallic conductors, and therefore transit time becomes appreciable. The upper frequency limit for satisfactory point-contact transistor operation is approximately 5 mc. When the electric field gradient is 1 volt per centimeter across the crystal, electron velocity in germanium crystals is of the order of 3600 centimeters per second, and hole velocity is of the order of 1700 centimeters per second.

Junction Transistors

The junction transistor (PNP and NPN) employs the same semiconductor materials as the point-contact transistor but is arranged in the form of a sandwich. The basic PN junction is used. However, such a junction cannot be made satisfactorily by simply bringing two surfaces together mechanically because of the difficulty in achieving the necessary smoothness and cleanliness of the surfaces to be joined. Instead, the junction is formed by a diffusion or alloy process, and by crystal growing.

GROWN-JUNCTION METHOD OF MANUFACTURE

The NPN junction transistor consists of a sandwich of P material between two layers of N material. This transistor cannot be formed satisfactorily by bringing two surfaces together mechanically because of the difficulty in achieving the necessary smoothness of the surfaces to be joined. Instead, the NPN transistor is formed by a GROWN-JUNCTION process. Germanium is obtained as a white powder, germanium dioxide (GeO_2). The powder is reduced to pure germanium by heating in an atmosphere of hydrogen. The pure powder is liquefied by further heating in an atmosphere of an inert gas similar to argon. The molten germanium is then allowed to cool slowly. Solid germanium is obtained in the form of bars several inches long and a square inch in cross-sectional area. In this condition, the germanium is polycrystalline and contains impurities.

The material is purified further by a process called "zone melting." In this process, impurities are removed satisfactorily. The bar will then have a satisfactorily high resistivity of approximately 60 ohms per cubic centimeter.

Single crystal germanium is obtained by a process called "pulling." In this process the purified germanium is melted in an atmosphere of inert gas, and into the melt is added an N-forming impurity such as arsenic. A single crystal germanium seed is then dipped into the melt and molten N-type germanium adheres to it. Then a small amount of P-forming impurity is added to the molten solution. This may be gallium or indium. The impurity rapidly diffuses through the melt and a P layer adheres to the crystal. After a definite time, the N-forming impurity, arsenic, is again added to the molten bath, thereby returning the bath to its original N-type germanium. As the germanium seed is slowly withdrawn, a layer of N-type germanium adheres to it. In this manner an NPN ingot is formed. It is then cut into a slab that is perpendicular to the long axis of the crystal. The slab is then diced into transistor pellets. The pellets are about 0.1 in. long and 0.03 in. thick. Each pellet comprises a junction transistor having two outside layers of N-type germanium separated by a P-type germanium section about .001 in. thick.

NPN CIRCUIT

The paths for current flow in an NPN junc-ion transistor are indicated in figure 11-8. The dotted battery symbols represent the po-ential hills. The emitter circuit is biased in he forward direction and the collector circuit s biased in the reverse, or high-resistance, irection.

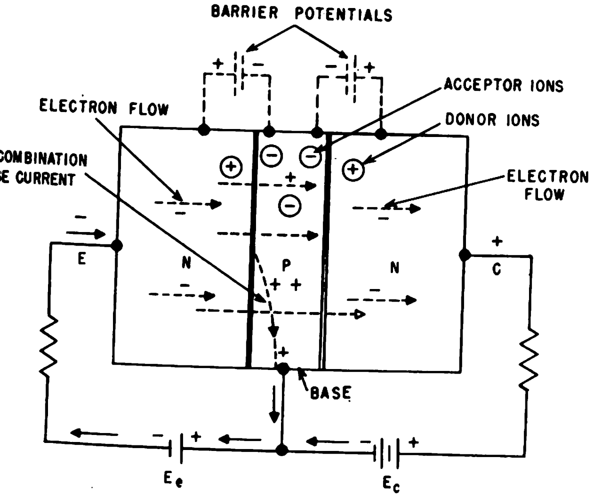


Figure 11-8.—NPN junction transistor.

Electrons flow in the external circuits of the itter and the collector in a clockwise direc-n. The emitter bias neutralizes the barrier ential across the emitter PN junction, thus owing electrons to be injected from the itter into the base region. P material has an ess of holes which, in this case, are called majority carriers. But when electrons are itted from the N-type emitter, they them-ves move through the P region of the base by a process known as diffusion. These electrons are also called minority carriers while in the base and may combine with holes, but most of them are collected by the positively biased collector.

As electrons move across the narrow P region of the base, a certain amount of recombination of electrons with holes will occur. This action will cause less increase in collector current for a given increase in emitter current. Thus, the current gain for a junction transistor, alpha (α), is less than unity.

The voltage and power gains of the NPN junction transistor are of about the same magnitude as those of the PNP junction transistor. These gains occur principally because the resistance of the collector circuit is high compared to the resistance of the emitter circuit.

ALLOY METHOD OF MANUFACTURE

The PNP junction transistor consists of a sandwich of N-type semiconductor material in between two layers of P material. The sandwich is formed by placing a BEAD of acceptor impurity such as indium on top of a flat square PELLET of N-type germanium about 0.05 in. on a side and 0.01 in. thick. The bead is placed at the center of the upper flat surface of the pellet, and the entire assembly is heated in an oven to a temperature above the melting point of the bead, but below that of the pellet. The heat causes the bead to partially diffuse into the pellet. The assembly is then removed from the oven and turned over. A second bead of indium is placed at the center of the flat pellet surface, and the heating process is repeated. The melting of the indium into the germanium crystal forms P-type germanium on either side of a centrally located N-type layer, which remains unchanged. By this diffusion process, a PNP junction is formed. The edges of the diffused region between the P and N materials form the boundaries across which the barrier potential is developed.

PNP CHARACTERISTICS

In the PNP transistor, conduction is by holes from the forward-biased emitter, through the base to the reverse-biased collector. Forward bias on the emitter junction repels the freed holes into the base. The holes will drift toward

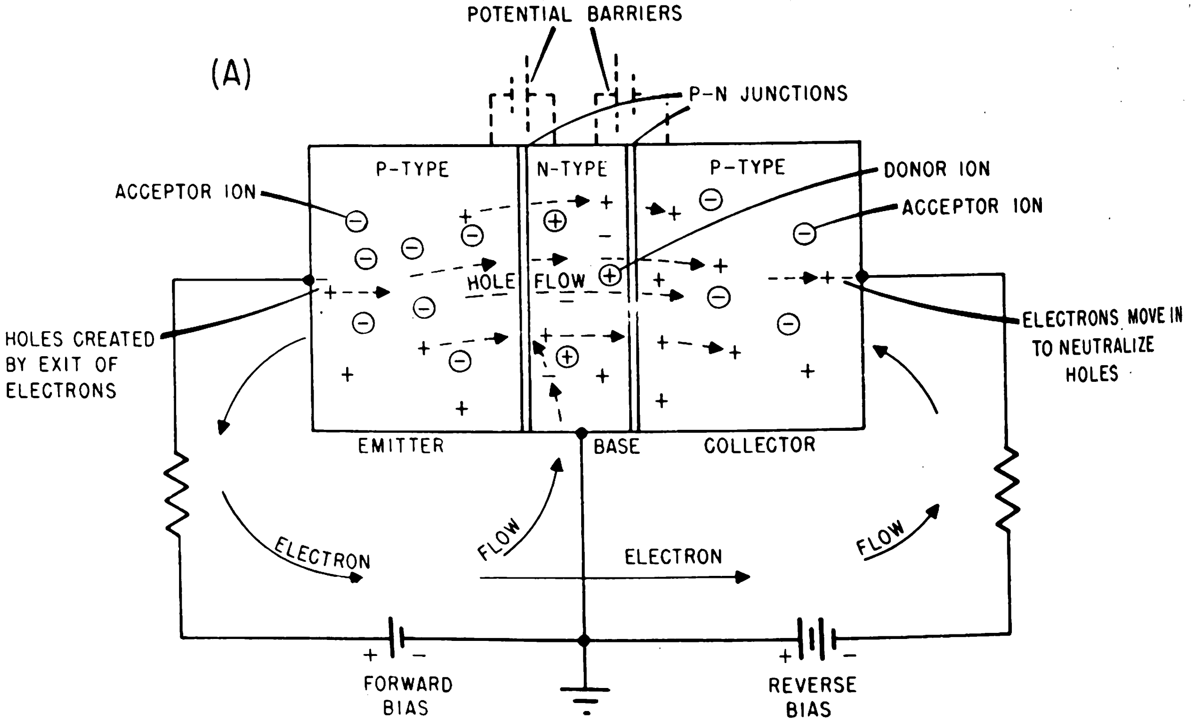


Figure 11-9(A).—Current flow in a PNP transistor.

the collector, accelerated by the negative charge of the base. Since the base is very thin (typical thickness 0.001 inch), most of the holes reach the collector. Recombination of holes and electrons takes place within the base region and becomes base current; however, there are very few electrons available for recombination due to the small amount of N-type material in the very thin base. Therefore, the base current is only a small percentage of the total current from the emitter.

Reverse bias on the collector junction prevents majority carrier conduction of that junction, and, collector current consists of holes from the emitter. In the external circuit, electron flow remains the basis of normal circuit analysis (fig. 11-9 (A)). It is considered that holes do not flow in the external circuit, but remain in the semiconductor material.

At the positive terminal of the emitter, holes are created as electrons leave the emitter. The holes then move toward the collector. As an electron leaves the emitter, one enters the collector and moves toward the emitter. Recombination of holes and electrons in the semiconductor occurs, and a continuous flow of current results.

Figure 11-9 (B) is a collector family of curves for a PNP transistor connected in the common-base configuration. (This corresponds to the plate family of curves of a vacuum tube.) A characteristic curve of I_C versus E_C with I_e held constant shows that as long as the collector

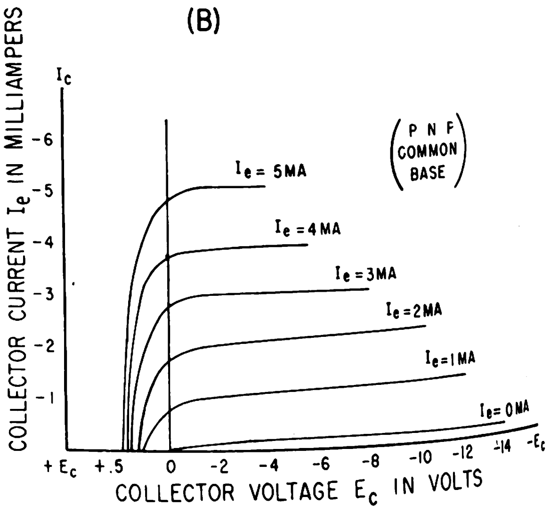


Figure 11-9(B).—PNP collector characteristics.

everse bias the collector current is con-
ed bv the emitter bias.
he normal region of operation is to the right
e knee of the curve. This is the region
the collector has reverse bias. Observa-
shows that a large change in collector
ge produces little change in collector cur-
This indicates that the collector's output
tance is very high. Also, it can be noted
vhen the collector voltage is zero, collector
nt still flows. This is due to the fact that
from the emitter are being driven into the
ctor by the force of the emitter's bias.
on applying a small amount of forward bias
collector (0.1 to 0.5 volt), the collector
ntly rapidly falls to zero. This happens be-
the collector attains an electrostatic force
and opposite to the holes from the emitter.
the collector current now equal to zero,
tire emitter current is shunted to the base.

TRANSISTOR AMPLIFIERS

The transistor amplifier and the electron-tube amplifier have somewhat similar circuit arrangements but widely differing characteristics. It is not possible to substitute one for the other without changing circuit components and bias and plate supply voltages. For example, the transistor in some circuits is a current amplifier and has a low impedance input; whereas, the corresponding electron-tube amplifier has a high impedance input. The three elements in a triode electron tube and the corresponding elements in a PNP junction transistor are illustrated in figure 11-10.

The transistors have a collector terminal that corresponds to the triode plate, a base terminal that corresponds to the triode grid, and an emitter terminal that corresponds to the triode cathode. In the PNP transistor the

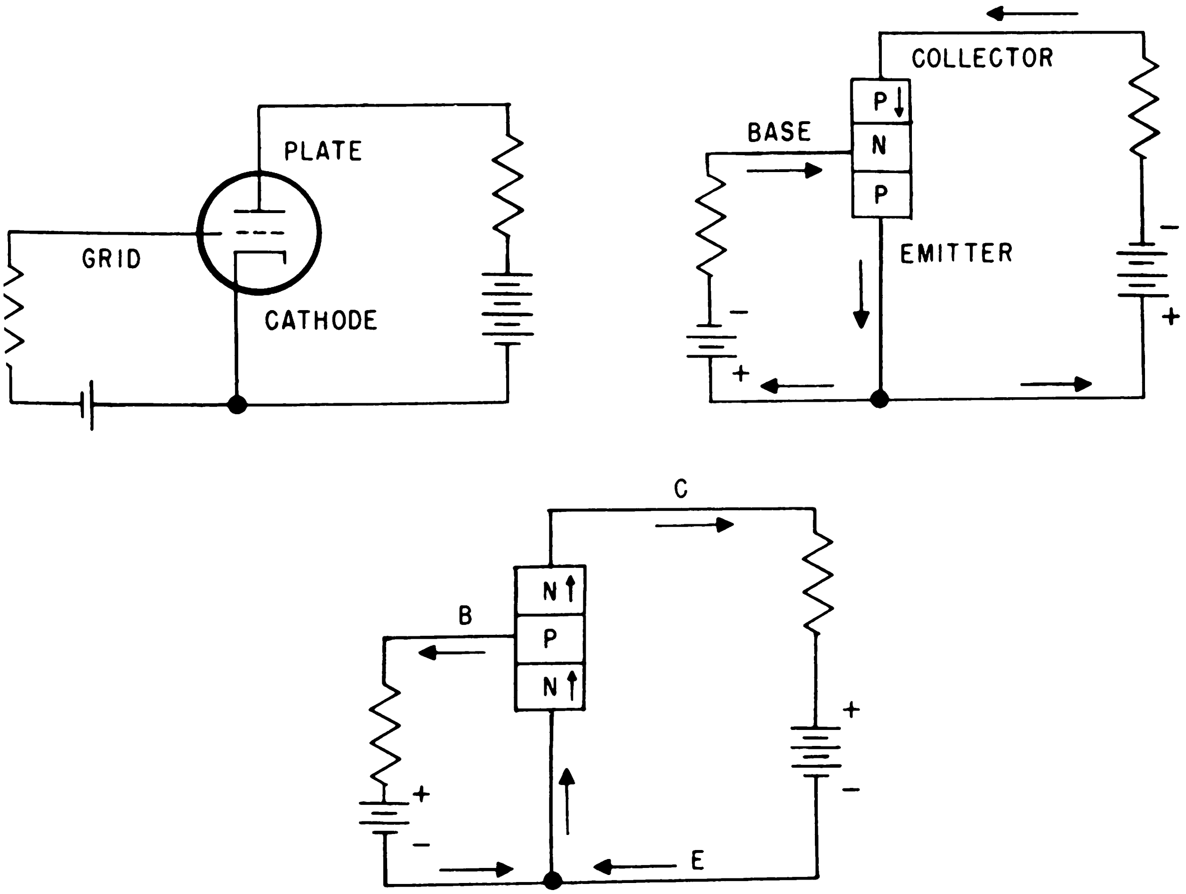
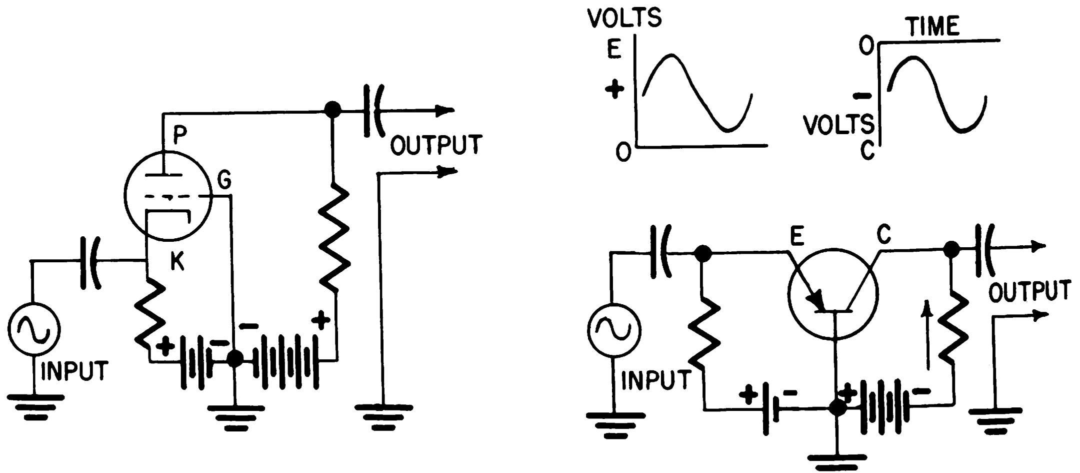
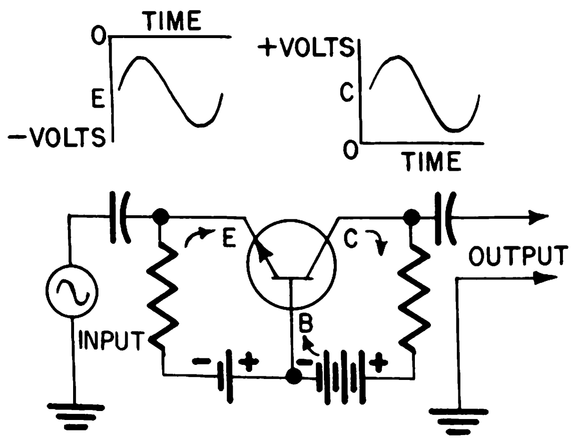


Figure 11-10.—Corresponding elements in triode and transistor.



(A) GROUNDED-GRID TRIODE

(B) GROUNDED-BASE PNP TRANSISTOR



(C) GROUNDED-BASE NPN TRANSISTOR

Figure 11-11.—Grounded-grid triode and corresponding grounded-base transistor amplifiers.

collector collects holes. In the NPN transistor the collector collects electrons.

Basic Circuits

The transistor amplifier may be connected in any one of three basic circuits. These circuits are the (1) grounded emitter, (2) grounded base, and (3) grounded collector. These three arrangements correspond respectively to three electron-tube basic circuits, namely: the (1) grounded cathode, (2) grounded grid, and (3) grounded plate amplifier. The significance of the expression "grounded" is that the element said to be grounded is, in reality, common to the input and output circuits and does not necessarily have to be grounded to provide satisfactory operation.

GROUNDED BASE

The grounded-base transistor amplifier is analogous to the grounded grid electron-tube amplifier. These circuits are illustrated in simplified form in figure 11-11. The grounded grid in the triode (fig. 11-11 (A)) is common to both the input and the output circuits. The grounded base in the PNP junction transistor (fig. 11-11 (B)) is common to both input and output circuits. (The terms, grounded and common, n be used interchangeably. EXAMPLE—ounded base is common base.)

The input signal to the triode is applied tween the cathode and ground and varies the ltage across the cathode resistor in series th the bias voltage source in the grid-cathode rcuit. The output signal is developed between ate and ground as a result of the variations plate current through the plate load im-dance. Effectively, the input signal is de-loped between the cathode and the grid and e output signal is developed between the ate and the grid. Hence, the grounded grid rms the common element between the input d output circuits. Plate current flows through e cathode resistor across which the input gnal is developed. The action is degenerative d lowers the gain of the amplifier compared that of a grounded-cathode amplifier.

The input signal to the transistor amplifier applied between the emitter contact, E, and ound and appears across the resistor in ries with the emitter base bias voltage. The erage value of the emitter-to-base voltage pends upon the magnitude of the bias voltage the input circuit. The output signal voltage developed between the collector and grounded se. The average value of the collector-to-ound voltage depends upon the magnitude of e collector supply voltage. The base of the ansistor is common to both input and output rcuits and need not necessarily be grounded, ovided the continuity of the common connec-n is maintained.

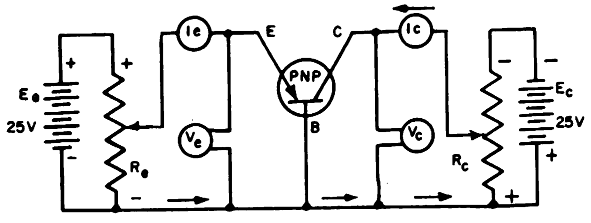
The input circuit bias polarity is in the ward, or low-resistance, direction of the itter-base junction. The magnitude of the s current determines the mode of operation the transistor amplifier, and the collector rent is primarily a function of the bias rent in the input circuit.

A distinctive characteristic of the grounded-e amplifier is that there is no polarity nge of the signal from the input to the output. positive-going input signal (fig. 11-11 (B)) aid the emitter-base-bias and increase the nitude of the emitter current accordingly. s action will increase both the collector rent and the voltage drop across the collector impedance with a consequent decrease in ector-to-ground voltage. The collector is itive with respect to ground, hence the de-se in negative voltage to ground is equiva-to a positive-going output signal.

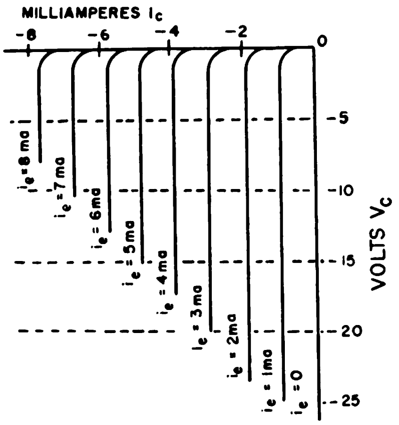
In the NPN transistor amplifier of figure 11-11 (C), a positive-going input signal will oppose the input bias and reduce the emitter current accordingly. This action will reduce both the collector current and the voltage drop across the collector load impedance with a resultant increase in collector voltage. Because the collector is positive with respect to ground, the increase in positive voltage is equivalent to a positive-going signal. Thus a positive-going input signal will cause a positive-going output signal in both PNP and NPN grounded-base amplifiers.

The input impedance of a grounded-base transistor amplifier is of the order of 100 ohms or less. The output impedance is relatively high—that is, of the order of 500 k—ohms for the junction transistor and 10 k—ohms for the point-contact transistor.

The relation between collector current and collector voltage for different values of emitter current is illustrated in figure 11-12 for a grounded base PNP junction transistor. The



(A) TEST CIRCUIT



(B) CHARACTERISTICS

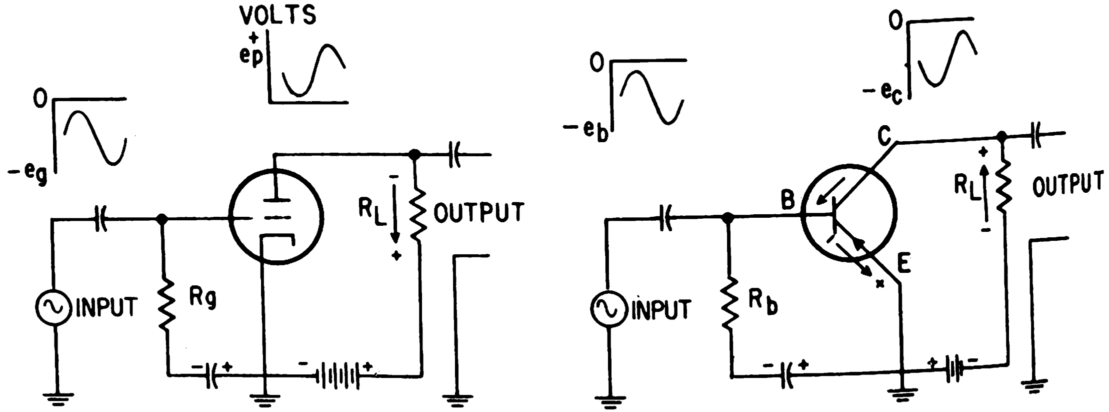
Figure 11-12.—Grounded-base transistor test circuit and collector characteristics for PNP junction.

circuit for determining the relation between these values is illustrated in figure 11-12 (A). Battery E_e and potentiometer R_e bias the emitter-base circuit in the forward, or low-resistance, direction for a PNP junction transistor. Moving the arm of R_e toward the positive terminal of R_e will increase the forward bias on the input circuit and therefore increase I_e and I_c. Moving the arm of R_c toward the negative end of R_c will increase the collector voltage.

Collector current is measured along the X axis and collector voltage is measured along the Y axis in the collector characteristic curves (fig. 11-12 (B)). These curves represent the relation between collector current and collector voltage for various values of emitter current. The curves indicate that the collector current is of the same order of magnitude as the emitter current and that the collector current is independent of collector voltage over most of the range of the curves. The current gain in the grounded-base junction transistor is less than 1, hence the voltage and power gain is caused by the increase in output resistance over that of the input circuit.

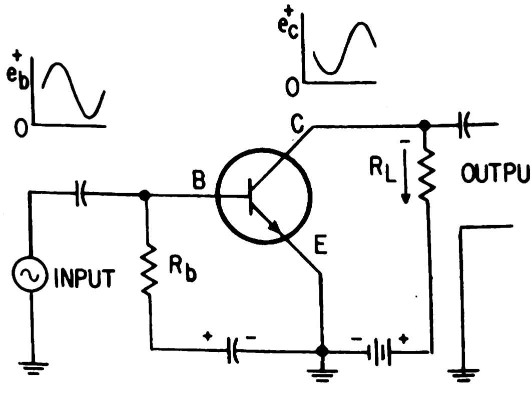
GROUNDED EMITTER

The widely used grounded cathode electron-tube amplifier and the corresponding grounded-emitter transistor amplifier are illustrated in figure 11-13. The transistor bias polarities



GROUNDED CATHODE AMPLIFIER
(A)

GROUNDED EMITTER PNP TRANSISTOR AMPLIFIER
(B)



GROUNDED EMITTER NPN TRANSISTOR AMPLIFIER
(C)

Figure 11-13.—Corresponding electron-tube and transistor amplifiers.

are established for a PNP junction transistor n figure 11-13, (B), and for an NPN junction ransistor in figure 11-13 (C).

The input signal to the triode (fig. 11-13 (A)) s developed across the grid resistor in series vith the bias voltage between the grid and athode. The output signal of the triode is deeloped between the plate and ground. The verage grid voltage depends upon the magniude of the grid bias supply voltage, and the verage plate voltage depends upon the magniude of the plate supply voltage.

The input signal to the transistor (fig. 11-13 3)) is developed between the base and emitter series with the bias voltage in this circuit. he bias polarity is in the forward, or low-esistance, direction of the base-emitter juncon. The output signal of the transistor is deloped between the collector terminal and ound. The average base voltage, as measured th respect to the emitter, depends upon the agnitude of the bias voltage in the base-itter circuit. However, the magnitude of the as current determines the mode (class) of eration of the transistor. The average coltor voltage depends upon the magnitude of the llector voltage supply. However, in many tances the magnitude of the collector voltage only a small effect in determining the coltor current. The collector current is pririly a function of the bias current in the input cuit.

When a signal is applied to the input circuit the transistor, the bias current varies about average, or no-signal, value. This action ses the collector circuit current to vary ough a much greater amplitude through the d impedance, which is connected in series n the collector voltage supply and the color terminal of the transistor.

A phase inversion occurs between the input output signals. Thus, a positive-going t signal (fig. 11-13 (B)) opposes the basecter bias and decreases the base-emitter ent. This action decreases the collector ent and voltage drop across the load imnce, resulting in an increase in collectorround output voltage. Because the collector egative with respect to ground, a positive-g input signal will result in a negative-g output signal.

positive-going input signal (fig. 11-13, will cause an increase in base-emitter curwith a corresponding increase in collector ent and voltage drop across the load impedance. Because this drop subtracts from the collector voltage, the output signal is less positive and is therefore equivalent to a negative-going output signal. The latter action is similar to that occurring in the plate circuit of the triode (fig. 11-13 (A)) with a positive-going signal on the grid. The increase in plate current causes an increased voltage drop in the plate load impedance with a resulting decrease in the plate-to-ground voltage. A decrease in the positive plate voltage is equivalent to a negative-going output signal

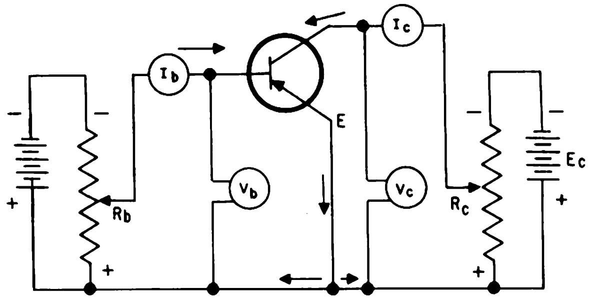
The ground-emitter transistor has a medium input impedance. For junction transistors, this value may be of the order of 1 k—ohm.

The output impedance of the grounded-emitter transistor may be of the same order of magnitude as the input impedance or higher, usually 10 k. to 100 k.

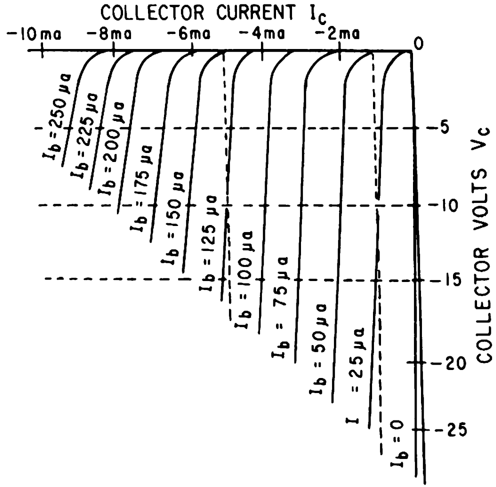
For a grounded-emitter PNP junction transistor, the relation between collector current and collector voltage for different values of emitter-base current, I_b, is illustrated in figure 11-14. The circuit for determining the relation between these values is illustrated in figure 11-14 (A). Battery E_b and potentiometer R_b bias the base-emitter input circuit in the forward, or low-resistance, direction for a PNP junction transistor. Moving the potentiometer arm of R_b toward the negative end of R_b will increase the forward bias on the input circuit and therefore will increase I_b and I_c. Moving the arm of potentiometer R_c toward the negative end of R_c will increase the collector voltage, V_c.

Collector current is measured along the X axis, and collector voltage is measured along the Y axis in the collector characteristic curves (fig. 11-14, (B)). These curves represent the relation between collector current and collector voltage for various values of emitter-base current. The curves indicate that collector current depends principally upon the magnitude of the emitter current and that, for a given value of emitter current, wide variations in collector voltage will have little effect on the magnitude of the collector current.

Current amplification is described in the following analysis. With the collector voltage, V_c, adjusted to -10 v. and the base current, I_b, adjusted to -25 μa, the collector current, I_c, will equal approximately -1 ma (1000 μa). Increasing I_b to -125 μa (with V_c constant) will increase the collector current to approximately -5 ma (5000 μa). Thus, an increase in input current of 100 μa will produce an increase in collector current of 4000 μa, or a current amplification of $\frac{4000}{100} = 40$.



(A) PNP TRANSISTOR GROUNDED EMITTER CIRCUIT



(B) TRANSISTOR CHARACTERISTICS

Figure 11-14.—Grounded-emitter PNP junction transistor static characteristics.

GROUNDED COLLECTOR

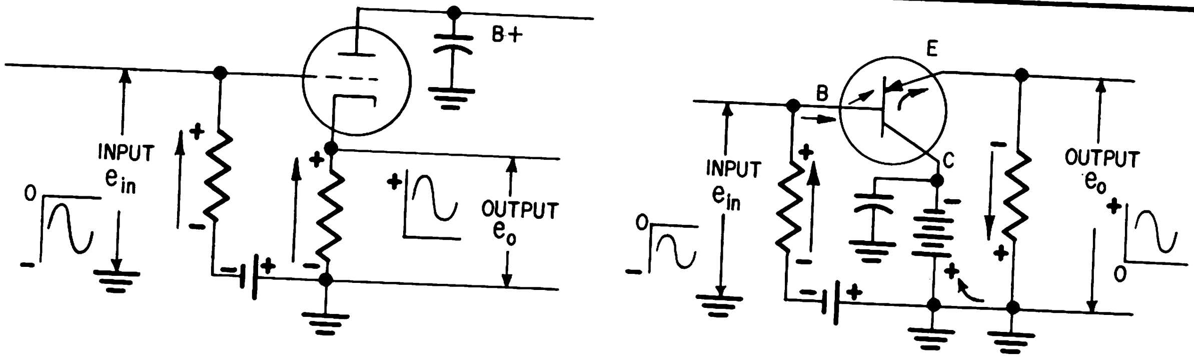
The grounded-collector transistor amplifier corresponds to the grounded plate electron-tube amplifier, or cathode follower. These circuits are illustrated in simplified form in figure 11-15. In the cathode follower the plate is at ground potential with respect to the signal component, and in the corresponding transistor circuits the collector is at ground potential with respect to the associated signal component. In the cathode follower the input signal is applied between the grid and the grounded side of the plate circuit, and the output signal is developed between the cathode and grounded side of the plate circuit. Thus the plate is common to the input and the output circuits.

In the grounded-collector transistor amplifier the input signal is applied between the base and the grounded side of the collector circuit. The output signal is developed between the emitter and the grounded side of the collector circuit. Thus the collector is common to the input and the output circuits.

Bias current is supplied by the single-cell source in series with the base-emitter circuit, and collector voltage is obtained from a battery consisting of several cells in series between the collector and ground. The base-emitter circuits are biased in the forward, or low-resistance, direction, and the collector-base circuits are biased in the reverse, or high-resistance, direction. Thus the input impedance of the grounded collector transistor is relatively high, because the input circuit includes the collector-base circuit with the bias in the high-resistance direction. The output impedance is relatively low because the output circuit includes the base-emitter circuit with its bias in the forward, or low-resistance, direction.

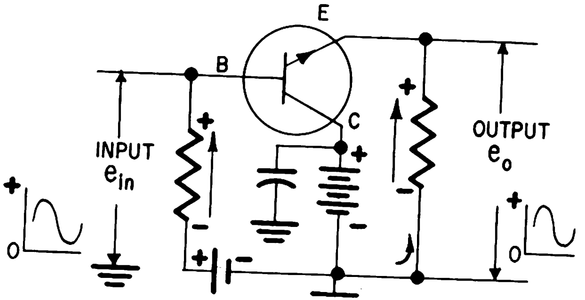
The input impedance of the electron-tube cathode follower is high and the output impedance is low, hence the cathode follower may be used as an impedance changer or stepdown transformer. The output signal, e_o, is in the series circuit between the cathode and grid and opposes the input signal, e_{in}, in the same circuit. Hence, the net voltage acting between the grid and cathode is $e_{in} - e_o$, and e_o must always be less than e_{in} if the grid-to-cathode voltage is to be a finite value. Thus the voltage gain of the cathode follower is always less than 1.

Similarly, the output signal in the grounded-collector transistor opposes the input signal, and the net signal voltage acting between the base and emitter is $e_{in} - e_o$. For example, if the input signal causes the voltage occurring between the base and ground to swing 10 mv in a positive direction and the output voltage between emitter and ground to swing 4 mv in the same direction, the net voltage between base and emitter will be 10-4 or 6 mv. The output voltage, e_o, must always be less than e_{in} if the base-to-emitter voltage is to be a finite value. Thus the voltage gain of the grounded-collector transistor, like that of the cathode follower, is always less than 1.



(A) CATHODE FOLLOWER

(B) GROUNDED COLLECTOR
PNP TRANSISTOR AMPLIFIER



(C) GROUNDED COLLECTOR NPN TRANSISTOR AMPLIFIER

Figure 11-15.—Electron-tube cathode follower and corresponding grounded-collector transistor amplifiers.

The grounded-collector transistor provides a
latively large current amplification and some
wer amplification, depending upon the magni-
e of the output impedance.

The input impedance of the grounded-
lector transistor amplifier is a function of
load impedance. This action is in contrast
that in the electron-tube amplifier in which
input and output circuits are isolated and
ctically independent of each other. For ex-
ple, the input impedance of a grounded-
ector junction transistor amplifier may be
he order of 150 k—ohms when the load
edance is 10 k—ohms, but the input im-
nce may drop to 50 k—ohms or less when
load impedance is reduced to 1000 ohms.

Class A grounded-emitter transistor audio
lifiers are operated so that collector cur-
flows during the entire input current cycle.
e correct operating point (load impedance)
input current are chosen, the output waveform will be essentially the same as the input in all respects, except for the amplitude.

Circuit Analysis

LOAD LINE

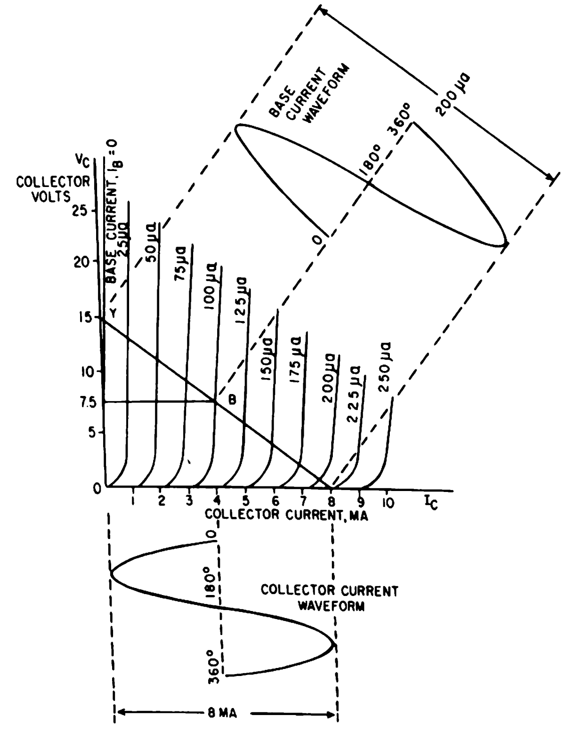
A simple method of determining the output voltage and current components of a transistor audio amplifier is by the use of the load line as illustrated in figure 11-16. The load line, XY, is a graph of the equation, $e_C = E_B - i_C R_L$, where e_C is the instantaneous collector-to-emitter potential, E_B is the collector supply voltage and $i_C R_L$ is the voltage drop across the load resistor, R_L.

Point Y is established as $e_C = E_B$. This condition exists when the collector current is zero, and the full value of the collector supply voltage appears between the collector and emitter because there is no voltage drop across R_L. In this example, the load line intersects the Y axis at Y = 15 v. Thus, E_B = 15 v.

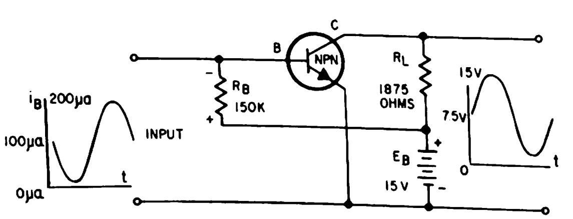
Point X is established as $i_c = \frac{E_B}{R_L}$. This condition exists when the base current is increased to the point where the effective internal resistance of the collector-emitter circuit is reduced to zero. For this condition the collector current would become a maximum value and the collector supply voltage would appear across the load resistance. In this example, the load line intersects the X axis at

$$i_c = \frac{E_B}{R_L} = \frac{15}{1875} = 0.008 \text{ amperes,}$$

or 8 ma.



CHARACTERISTICS



CIRCUIT

Figure 11-16.—Transistor class A audio amplifier.

LOAD RESISTANCE

The load resistance, R_L, is equal to the slope of the load line and may be determined as

$$\frac{E_B - E_c}{I_c}$$

where E_c is the collector-to-emitter voltage at the operating point B, and I_c is the collector current at this point.

In this example,

$$R_L = \frac{15 - 7.5}{0.004} = 1875 \text{ ohms.}$$

BIAS

With the operating point at B (no-signal condition) the base-emitter bias voltage necessary to cause a base current of 100 μa may be obtained from the collector supply voltage by connecting a resistor of the proper magnitude between the base and the positive terminal of E_B. The magnitude of this bias resistor will be

$$R_B = \frac{E_B}{i_B} = \frac{15}{100 \times 10^{-6}} = 150,000 \text{ ohms.}$$

This value includes the emitter-to-base resistance, which is only a few hundred ohms and can be neglected in the calculation. Resistor R_B limits the base-emitter current in the forward direction to approximately 100 μa. However, the bias is not developed across R_B, but is developed across the junction as a result of the flow of no-signal current through the transistor between the emitter and the base. This action makes the emitter negative with respect to the base. This polarity indicates the forward direction for the base-emitter circuit of the NPN junction transistor, and is not to be confused with the polarity of the voltage drop across R_B, which is opposite to the proper bias polarity. Certain instabilities common to this bias method are described later.

The d-c operating point, B, indicates that the collector current will be 4 ma when the collector-to-emitter potential is 7.5 v., and the base current is 100 μa. The voltage drop across R_L for this condition is i_cR_L, or 0.004 x 1875 = 7.5 v, and the collector potential is $E_B - i_cR_L$, or

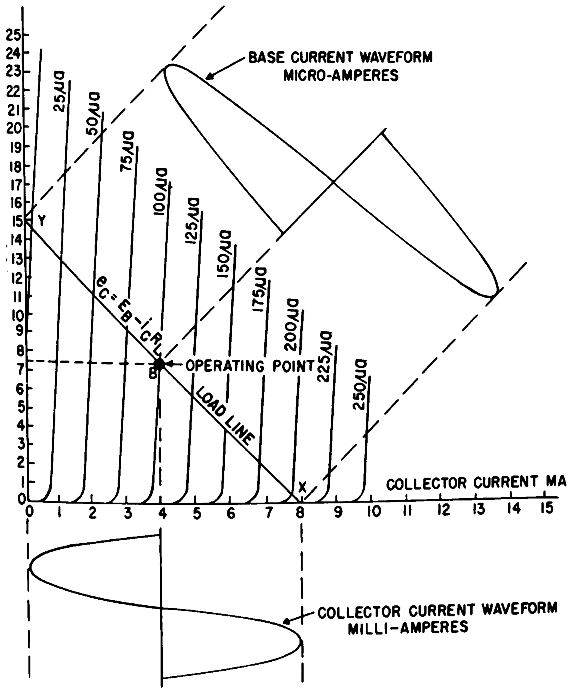
- 7.5 = 7.5 v. The no-signal base current this condition is

$$i_B = \frac{15}{0.150 \times 10^6} = 100 \times 10^{-6} \text{ amperes},$$

100 μa.

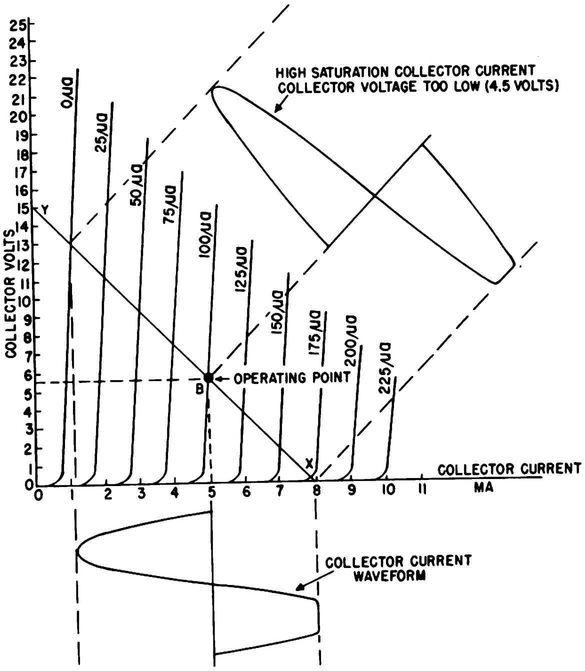
If the signal voltage applied across the input minals has a peak magnitude slightly less n that of the voltage drop across the emitter-base circuit (E to B) and the polarity is posite to that of the forward, or low-sistance, direction of electron flow, the base rent will be reduced. In this example the ut signal current is assumed to be of sine veform and of such a magnitude as to vary base current from 100 μa (no-signal value) zero, to 100 μa for the first half cycle. For second half cycle the base current is varied m 100 μa to 200 μa and back to 100 μa.

When the base current is reduced to zero, the lector current will be reduced to zero, and collector voltage will increase to approxi-tely 15 v. When the base current is in-eased to 200 μa, the collector current will rease to approximately 8 ma, and the collector voltage will be reduced to almost zero. Thus, the output voltage will vary sinusoidally about a no-signal value of 7.5 v and will have a peak-to-peak value of approximately 15 v.



(A) NORMAL TEMPERATURE

igure 11-17(A).—Effect of temperature variations on NPN transistor characteristics.

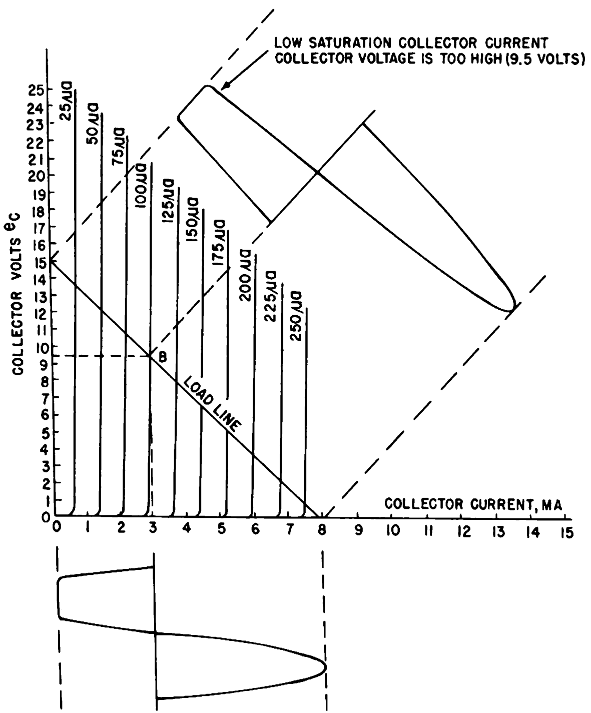


(B) INCREASED TEMPERATURE

Figure 11-17(B).—Effect of temperature variations on NPN transistor characteristics—Continued.

The characteristics of transistors will change with temperature variations. Figure 11-17 (A) represents the constant base current curves of collector volts versus collector current for normal temperature operation. Figure 11-17 (B) represents the curves for the same transistor with above normal temperature operation. The effect of increased temperature moves the curves to the right along the X axis, and may increase the spacing between them. This action shifts the operating point, B, on the load line toward point X, making the collector voltage too low. The normal collector voltage for class A operation, point B (fig. 11-17 (A)) is 7.5 v. The increase in temperature moves point B to a point indicated in figure 11-17 (B) that corresponds to a collector voltage of 5.5 v.

Conversely, the effect of a decrease in temperature moves the curves to the left along the X axis and reduces the spacing between them



(C) DECREASED TEMPERATURE

Figure 11-17(C).—Effect of temperature variations on NPN transistor characteristics—Continued.

(fig. 11-17 (C)). This action shifts the operating point along the load line toward point Y, making the collector voltage too high. The operating point now corresponds to a collector voltage of 9.5 v.

The apparent shift of the operating point will not only cause distortion of the output signal, but in the case of increased temperature the increased collector current may cause the transistor to burn out. The condition may be partially remedied by connecting the bias resistor directly between the collector and base as illustrated in figure 11-18. In this circuit, R_B provides self bias for the transistor base-emitter circuit. As seen by tracing the heavy lines, R_B is in series with the base-emitter circuit. In the previous example the no-signal operating point corresponds to a collector voltage of 7.5 v. and a base-emitter current of 100 μa. For this condition,

$$R_B = \frac{E_c}{i_B} = \frac{7.5}{100 \times 10^{-6}} = 75,000 \text{ ohms.}$$

As in the fixed bias arrangement, the polarity of the voltage drop across the base-emitter junction is such as to make the emitter negative, with respect to the base. This polarity corresponds to the forward direction for the base-emitter NPN junction transistor.

With this type of self bias, a change in temperature will affect the magnitude of the bias current. For example, if an increase in temperature occurs, the tendency for the collector current to increase will be accompanied by a decrease in collector voltage across R_B with a corresponding decrease in base bias current

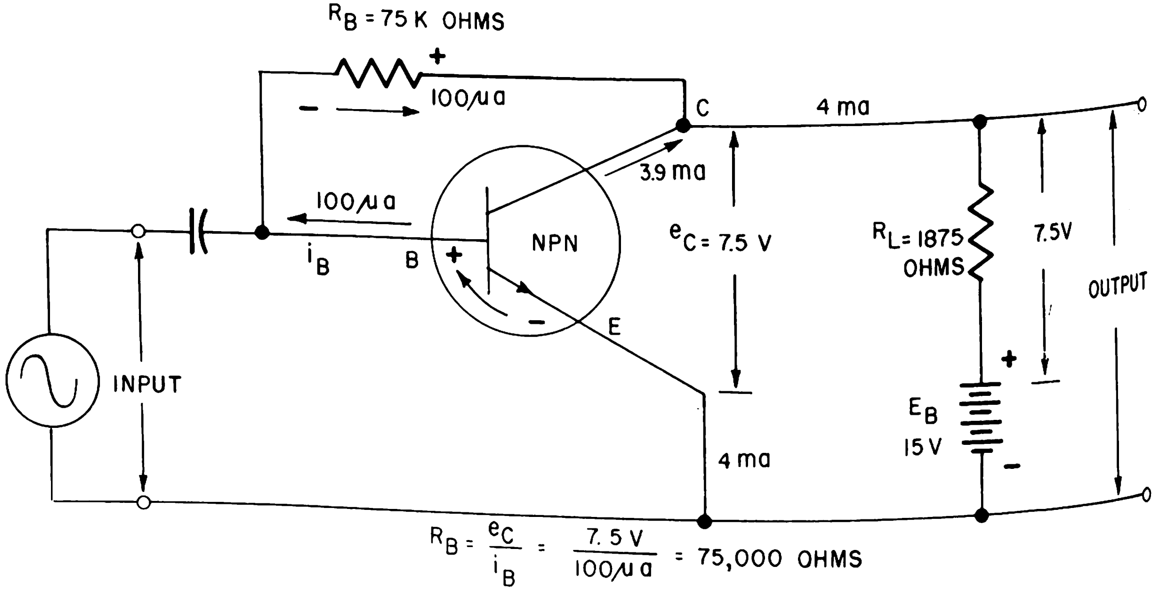


Figure 11-18.—Transistor self bias.

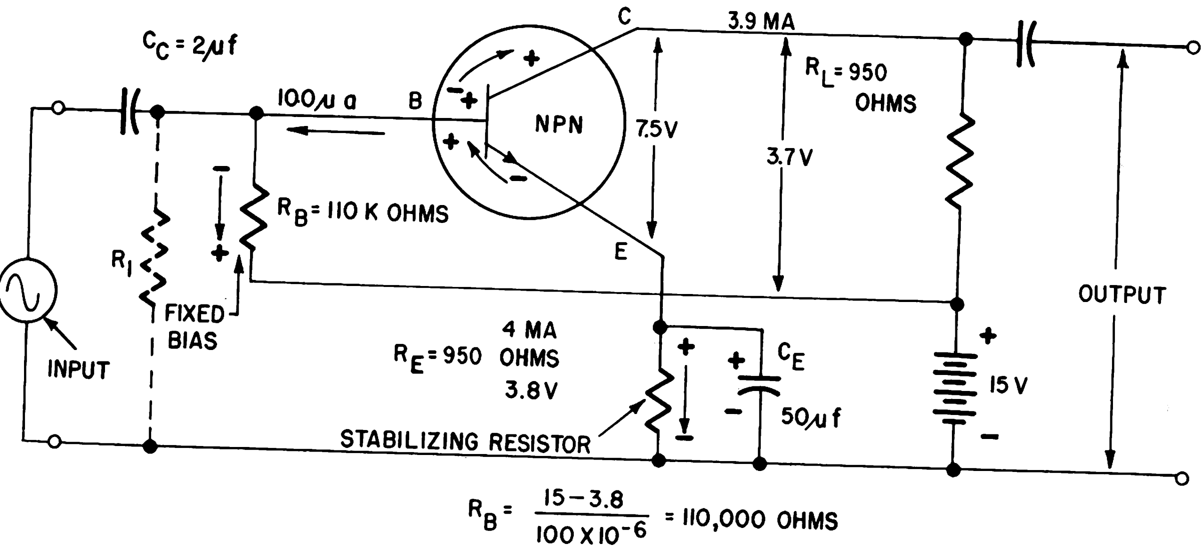


Figure 11-19.—Transistor amplifier with fixed bias and circuit stabilization.

gh R_B. This action will tend to shift the ting point along the load line upward to the f point B (fig. 11-17 (B)) and thus to reduce mount of distortion caused by the temperancrease.

onversely, a decrease in temperature will companied by a tendency for the collector nt to decrease and the collector voltage s R_B to increase. The increase in voltage s R_B will increase the base bias current gh R_B and shift the operating point along ad line downward and to the right of point g. 11-17 (C)). This action will again relistortion.

us, self bias provides an action that tends artially compensate for temperature es. In addition, self bias provides negative ck similar to that provided by an unby- cathode resistor in an electron-tube ler. This action reduces the effective gain transistor amplifier.

he transistor amplifier illustrated in 11-19, resistor R_B provides fixed bias ss A operation, and resistor R_E provides stabilization to prevent temperature s from altering the transistor character- Resistor R_E also prevents damage to nsistor by limiting the magnitude of the or current to the maximum safe value for the highest temperature to be encountered during operation.

If the temperature increases, the increase in collector current through R_E will lower the emitter voltage. This action will tend to prevent further increase in collector current and therefore will prevent the shift of the characteristic curves to the right along the X axis (fig. 11-17) (B)). Conversely, a decrease in temperature will lower the collector current through R_E and the voltage drop across R_E. This action will increase the collector voltage and will tend to prevent further reduction in collector current so that there will be less shift of the characteristic curves to the left along the X axis (fig. 11-17 (C)).

The value of R_E is equal to the value of R_L for maximum protection. In this case the efficiency is reduced from 50 percent in figure 11-18 for maximum power output to 25 percent in figure 11-19. As transistors become more uniform with improved methods of manufacture, the allowable tolerances will be reduced. Thus when a transistor is replaced in a circuit, it will be more nearly like the replacement transistor, and the need for this amount of circuit stabilization will be reduced. It is believed that most transistor audio power amplifier circuits will be satisfactorily stabilized if the value of R_E is not more than 10 percent of the load resistance for maximum power output. In the preceding example of figure 11-18 according to this relation, $R_E = 0.1 \times 1880$, or 188 ohms, and the power dissipated in R_E will be 10 percent of the power output of the stage.

If resistor R_1 is added to the circuit of figure 11-19, another return path for collector current will be provided. This path is around R_E. If R_1 is a relatively low resistance compared to R_E, most of the collector current will flow through R_1. This action reduces the signal component of collector current through R_E with less degeneration and increased stage gain. On the other hand more power will be wasted at the input, but there will be less change in input impedance and less change in input circuit loading.

CAPACITORS

In order to prevent degeneration from occurring across the stabilizing resistor, R_E (fig. 11-19), in the emitter circuit, a bypass capacitor, C_E, is connected in parallel with R_E. The action is similar to that occurring in the cathode bypass capacitor in parallel with the cathode resistor of a cathode biased electron-tube amplifier. In order to bypass the a-c component around the resistor without developing a voltage at the signal frequency across the resistor, the X_c ohms of the bypass capacitor should be low with respect to the resistance of the resistor. For most audio transistor amplifiers the bypass capacitor does not need to be larger than about 50 μf.

The coupling capacitor, C_c, must be large enough to pass the lowest frequency signal without appreciable phase shift or reduction in magnitude of the signal. The lowest frequency to be passed is the frequency at which there is a reduction in amplitude of 3 db. At this frequency the X_c ohms of the coupling capacitor are equal approximately to the input resistance of the transistor amplifier stage. In the example of figure 11-19, the input resistance is approximately 1000 ohms and consists essentially of the resistance between the transistor base and emitter in the forward, or low-resistance, direction. If the lowest frequency to be passed is 100 cycles per second, the X_c ohms of C_c will equal the input resistance, or 1000 ohms. The capacitance of the coupling capacitor is found as follows:

$$C_c = \frac{10^6}{6.28 \times X_c} = \frac{10^6}{6.28 \times 100 \times 1000} = 1.59\ \mu\text{f}.$$

A 2 μf capacitor would extend the low frequency limit to about 80 cycles per second.

VOLTAGE AND CURRENT DISTRIBUTION

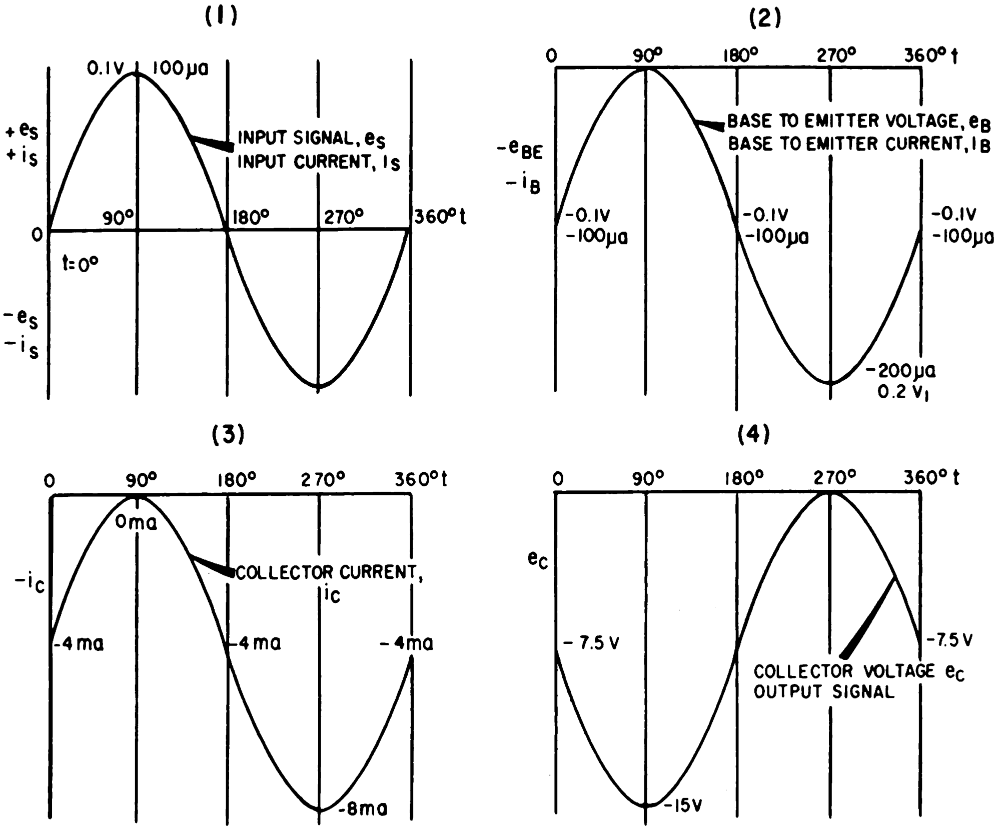
The action of a transistor amplifier will now be given with respect to the distribution of the voltages and currents through the input and output circuits before and after a signal is applied.

Figure 11-20(B) illustrates a transformer coupled junction transistor audio amplifier stage employing the grounded emitter as the common element between input and output circuits and a single battery for collector supply voltage and base-emitter bias. The sine waveforms of signal current and voltage are illustrated in figure 11-20 (A).

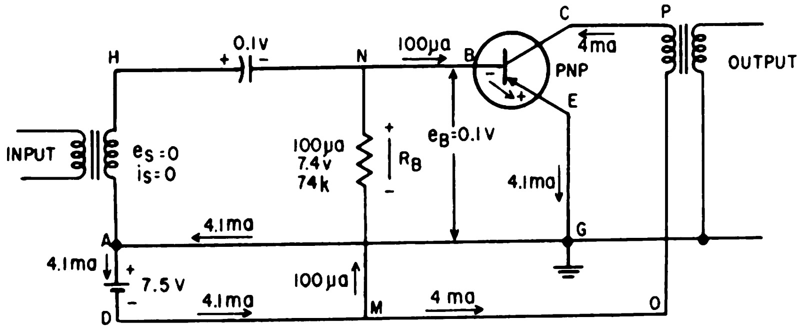
The circuit analysis is made for three different instants of time occurring within one complete cycle of applied signal. These instants are when (1) t = 0°, (2) t = 90°, and (3) t = 270°.

At the instant when t = 0°, the input signal voltage is zero, and the 7.5-volt battery supplies the no-signal base-emitter bias current of 100 μa and the no-signal collector current of 4 ma. The distribution of voltages and currents is illustrated in figure 11-20 (B). Only the input circuits are analyzed in detail. Kirchhoff's law of voltages is applied to three closed circuits, all on the input side of the transistor. The algebraic sum of the instantaneous voltages around these circuits is equated to zero. If the algebraic sum of the numerical values is zero, the voltages are assumed to be correct.

The first circuit to be traced starts at point A and includes the 7.5-volt battery, the bias resistor, R, the base, B, of the transistor, the emitter, E, and returns to the battery at the starting point, A. The circuit trace is designated as ADMNBEGA. The designation for the algebraic sum of the voltages, Σ (sum) volts = 0, identifies the individual circuit by means of the subscripts following the symbol, Σ. These letters appear on the amplifier circuit (fig. 11-20, (B), (C), and (D)). Thus the equation that



(A) WAVEFORMS



t=0°

$e_S=0,\ i_S=0,\ e_{BE}=0.1V$

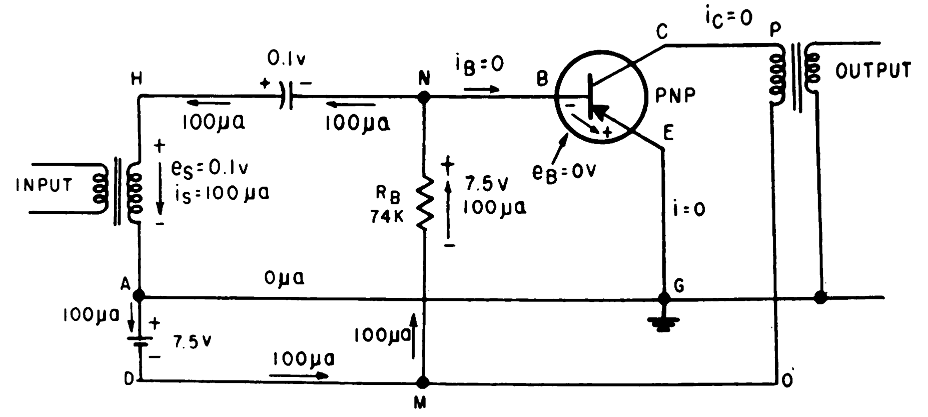
(1) $\Sigma\, \text{VOLTS}_{ADMNBEGA}=0 \quad 7.5-7.4-0.1=0$

(2) $\Sigma\, \text{VOLTS}_{HAGEBNH}=0 \quad 0+0.1-0.1=0$

(3) $\Sigma\, \text{VOLTS}_{HADMNH}=0 \quad 0+7.5-7.4-0.1=0$

(B) VOLTAGE AND CURRENT DISTRIBUTION WHEN t = 0°

Figure 11-20.—Circuit analysis for junction transistor amplifier having a common battery supply for input and output circuits.



t = 90°

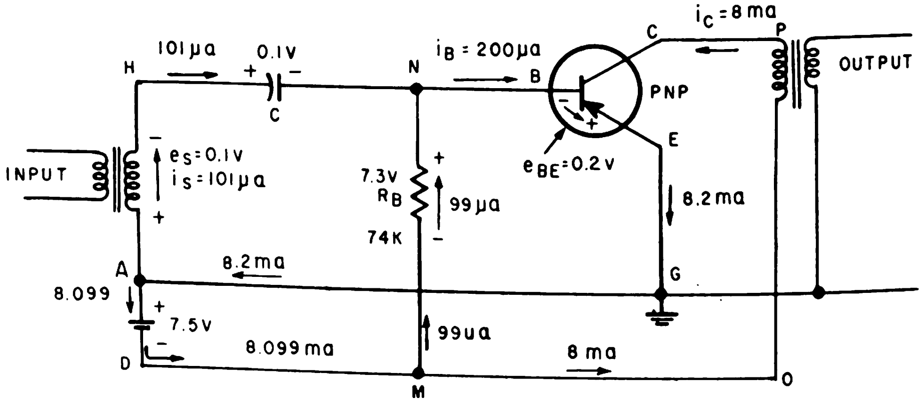
$e_S = +0.1v \quad i_S = 100\mu a \quad e_{BE} = 0$

(1) $\sum_{ADMNBEGA} VOLTS = 0 \quad 7.5 - 7.5 - 0 = 0$

(2) $\sum_{HAGEBNH} VOLTS = 0 \quad 0.1 + 0 - 0.1 = 0$

(3) $\sum_{HADMNH} VOLTS = 0 \quad 0.1 + 7.5 - 7.5 - 0.1 = 0$

(C) VOLTAGE AND CURRENT DISTRIBUTION WHEN t = 90°



t = 270°

$e_S = 0.1v \quad i_S = 101\mu a \quad e_{BE} = 0.2v \quad i_B = 200\mu a$

(1) $\sum_{ADMNBEGA} VOLTS = 0 \quad 7.5 - 7.3 - 0.2 = 0$

(2) $\sum_{HAGEBNH} VOLTS = 0 \quad 0.1 + 0.2 - 0.1 = 0$

(3) $\sum_{HADMNH} VOLTS = 0 \quad 0.1 + 7.5 - 7.3 - 0.1 = 0$

(D) VOLTAGE AND CURRENT DISTRIBUTION WHEN t = 270°

Figure 11-20.—Circuit analysis for junction transistor amplifier having a common battery supply for input and output circuits—Continued.

applies to

$$\sum_{ADMNBEGA} VOLTS = 0$$

is derived by tracing the circuit ADMNBEGA and equating the algebraic sum of the voltages equal to zero in this circuit. The voltage equation for this circuit is 7.5-7.4-0.1 = 0. The first term is the battery voltage. The second term is the drop across R_B, and the third term is the drop across the base-emitter junction.

From this equation it may be seen that the base-emitter no-signal bias current is limited principally by resistor R_B because most of the battery voltage appears across R_B. It may also be seen that the voltage drop across the base-emitter terminals of 0.1 v in the forward direction with a base-emitter current of 100 μa or 0.1 ma will indicate a base-emitter resistance of $\frac{0.1 \text{ v}}{0.1 \text{ ma}}$, or 1 k-ohm. Capacitor C blocks the d-c component of voltage and current across the base-emitter junction from the secondary of the input transformer and charges up to the peak voltage drop across the junction. Capacitor C is relatively large (2 mf), and the voltage across C is assumed to remain at 0.1 v. through the entire cycle of applied signal voltage.

The second voltage equation for the instant when t=0° is derived by tracing around the circuit HAGEBNH and equating the algebraic sum of the instantaneous voltages to zero. Thus the equation that applies to $\sum_{\text{HAGEBNH}} \text{VOLTS} = 0$ is 0.0+0.1 - 0.1 = 0. The first term is zero because at the instant t = 0°, the signal voltage is zero. The second and third terms are of opposite signs indicating that the capacitor voltage is opposed by the voltage drop occurring between the base and the emitter. As mentioned previously, C will block the d-c component of base-emitter current and voltage from the secondary of the input transformer.

The third voltage equation for the instant when t=0° is derived by tracing around the circuit HADMNH and equating the algebraic sum of he instantaneous voltages to zero. Thus the equation that applies to $\sum_{\text{HADMNH}} \text{VOLTS} = 0$ is 0.0 7.5-7.4-0.1 = 0. The first term is zero because he signal voltage is zero when t = 0°. The second erm is 7.5 v, representing the battery terminal oltage. The third term is 7.4 v, representing he voltage drop across the bias resistor, R_B. The last term is 0.1 v, representing the voltage cross C.

The no-signal condition upon which the preeding three equations depend may be regarded s the operating point, B (fig. 11-16 (A)) on the oad line, XY. The load impedance (noninductive) assumed to be the slope of the load line, or 375 ohms. The principal difference between the xample of figure 11-20 and that of figure 11-16 that the load resistor of figure 11-16 has been eplaced by a transformer having negligible d-c sistance in its windings so that the collector voltage supply may be reduced from 15 v to 7.5 v, without changing the slope of the load line. Thus, the non-signal collector current of 4 ma that flows through the primary of the output transformer produces a negligible d-c voltage drop across the primary, and the collector voltage for this condition is 7.5 v.

During the interval between 0° and 90° the input signal voltage increases from 0 to a positive maximum value of 0.1 v, and the input signal current increases from 0 to 100 μa as represented by curve (1) of figure 11-20 (A). During this interval, the base-emitter current decreases from 100 μa to 0, curve (2), and the collector current decreases from 4 ma. to 0, curve (3). At the same time, the induced voltage acting in the primary of the output transformer causes the collector voltage to increase from -7.5 v to -15 v, curve (4).

At the instant t = 90° (fig. 11-20 (C)) the input signal voltage is a positive maximum value of 0.1 v. The polarity of the signal voltage indicates that this voltage acts across the base-emitter junction in the backward, or high-resistance, direction, hence no base current will flow. Instead, signal current will flow through the secondary of the input transformer in series with the battery, the bias resistor, R_B, and the capacitor, C. The signal voltage acts in series additively with the battery voltage, thereby increasing the voltage drop across R_B from 7.4 v to 7.5 v. During the interval from 0° to 90° the base current decreases from 100 μa to 0 as the signal current increases from 0 to 100 μa. This action indicates that an approximately constant current flows through R_B into junction N. As the current flow into the base, B, decreases, the current flow into the capacitor circuit, NH, increases. It is assumed that the capacitor is sufficiently large so that the flow of signal current through the circuit from N to H will not increase the voltage drop across the capacitor to any appreciable extent.

The voltage equation for the instant when t = 90° that corresponds to the designation

$$\sum_{\text{ADMNBEGA}} \text{VOLTS} = 0 \text{ is } 7.5-7.5-0=0.$$

The slight increase in voltage across the 7.4 k-ohm resistor, R_B, from 7.4 v to 7.5 v produces a negligible increase in current through R_B and a decrease in voltage across the base-emitter junction from -0.1 v to 0, (curve (2) fig. 11-20 (A)).

The voltage equation for the instant when t = 90° that corresponds to the designation $\sum_{\text{HAGEBNH}} \text{VOLTS} = 0$ is 0.1+0-0.1=0. The first term represents the peak positive signal voltage occurring across the secondary of the input transformer. The second term represents the zero voltage across the base-emitter junction, curve (2), and the third term represents the constant voltage across capacitor C.

The voltage equation for the instant when t=90° that corresponds to the designation $\sum_{\text{HADMNH}} \text{VOLTS} = 0$ is 0.1+7.5-7.5-0.1=0. The peak positive input signal current flows in a counterclockwise direction around this circuit.

During the interval from 90° to 180° the input signal voltage decreases from positive maximum to 0 (curve (1) (fig. 11-20 (A)). At the same time the voltage drop across R_B decreases from 7.5 v to 7.4 v, and the base-emitter voltage increases from 0 to -0.1 v, curve (2). Thus during the first half cycle (0° to 180°) of applied signal, the base-emitter current varies sinusoidally through a maximum change of 100 μa.

In the collector circuit the collector current also varies sinusoidally through a maximum change of 4 ma as the collector voltage varies sinusoidally through a maximum change of 7.5 v, curves (3) and (4).

The input signal voltage for the second half cycle is of opposite polarity to that for the first half cycle, curve (1). Thus the signal voltage opposes the battery voltage and lowers the voltage drop across R_B to 7.3 v at the instant when t = 270°. At this instant, the signal voltage acting in series addition with the capacitor voltage develops a voltage of -0.2 v across the base-emitter junction in the forward or easy direction of current flow. Thus the base current increases to a peak of -200 μa. This action causes the collector current to increase to a maximum value of -8 ma, as the self-induced voltage in the output transformer primary causes the collector voltage to swing to zero, curves (3) and (4).

The voltage equation for the instant when t = 270° that corresponds to the designation $\sum_{\text{ADMNBEGA}} \text{VOLTS} = 0$ is 7.5 - 7.3 - 0.2 = 0 (fig. 11-20 (D)). The current flow through R_B decreases slightly from 100 μa to 99 μa. The signal current flowing into junction N from terminal H increases from 0 to 101 μa and combines with the bias current flowing through R_B into junction N to increase the base-emitter current from -100 μa to -200 μa, curve (2). This current returns to junction A where it divides almost equally, with 101 μa returning to the secondary of the input transformer and 99 μa returning to the battery.

The voltage equation for the instant when t = 270° that corresponds to the designation $\sum_{\text{HAGEBNH}} \text{VOLTS} = 0$ is - 0.1 + 0.2 - 0.1 = 0. The first term of this equation represents the signal voltage. The second term represents the voltage across the emitter-base junction, and the third term represents the voltage across the capacitor.

The voltage equation for the instant when t = 270° that corresponds to the designation $\sum_{\text{HADMNH}} \text{VOLTS} = 0$ is -0.1 + 7.5 - 7.3 - 0.1 = 0. As the voltage across R_B decreases from 7.4 v to 7.3 v, the voltage across the base-emitter junction increases from -0.1 v to -0.2 v in the forward direction of the base-emitter circuit. The second half cycle is completed as the signal voltage decreases from negative maximum to 0, the base-emitter current decreases from -200 to -100 μa, and the collector current decreases from -8 ma to -4 ma and the collector voltage swings from 0 v. back to -7.5 v.

The peak-to-peak signal voltage appearing across the primary of the output transformer is 15 v. The peak-to-peak signal component of current .through the primary of the output transformer is 8 ma. The power output of the amplifier is $e_{rms} i_{rms}$, or $\frac{15}{2} \times 0.707 \times \frac{8}{2} \times 0.707 = 15$ mw.

Cascade Amplifiers

SINGLE-ENDED CONNECTIONS

Transistor amplifier stages may be connected in cascade as illustrated in figure 11-21. TR1 and TR2 are PNP junction transistor audio voltage amplifiers, and TR3 is a PNP junction transistor power amplifier. Transformer T1 is a stepdown matching transformer that couples a high-impedance microphone to a low-impedance input circuit. Interstage coupling transformers T2 and T3 match the output impedance of one stage to the input impedance of

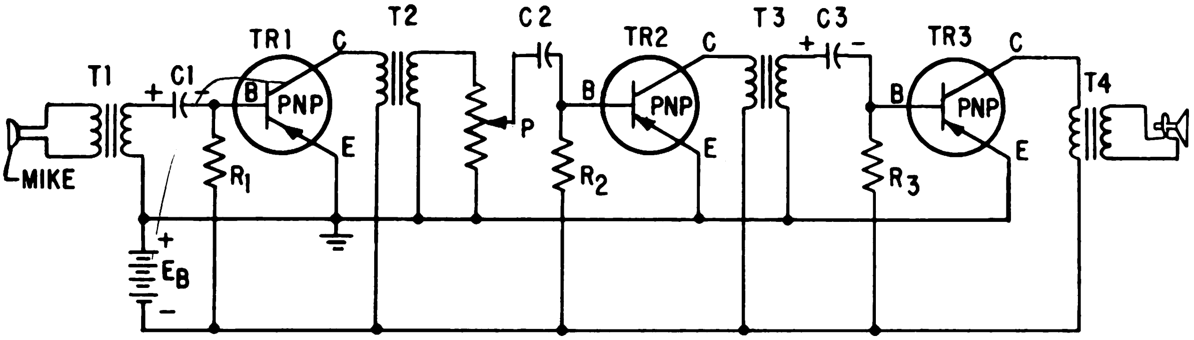


Figure 11-21.—Cascade connection of transistor amplifiers.

the next. These impedances are not widely different. For example, the output impedance of TR1 may be 20,000 ohms and the input impedance of TR2 may be 1000 ohms. Transformer T4 is a stepdown transformer that couples the output signal in the collector circuit of the third stage to the low-impedance voice coil of the reproducer. Capacitors C1, C2, and C3, block the d-c bias from the secondaries of T1, T2, and T3 and couple the signal to the input circuits. Potentiometer P serves as a volume control for the amplifier. Volume increases as the arm is moved toward the upper end of T2. Resistors R1, R2, and R3 limit the no-signal base-emitter bias current to the proper value for each stage. The grounded emitter is common to all input and output circuits, and the polarities of the input and output d-c voltages for each stage correspond to those required by PNP junction transistors.

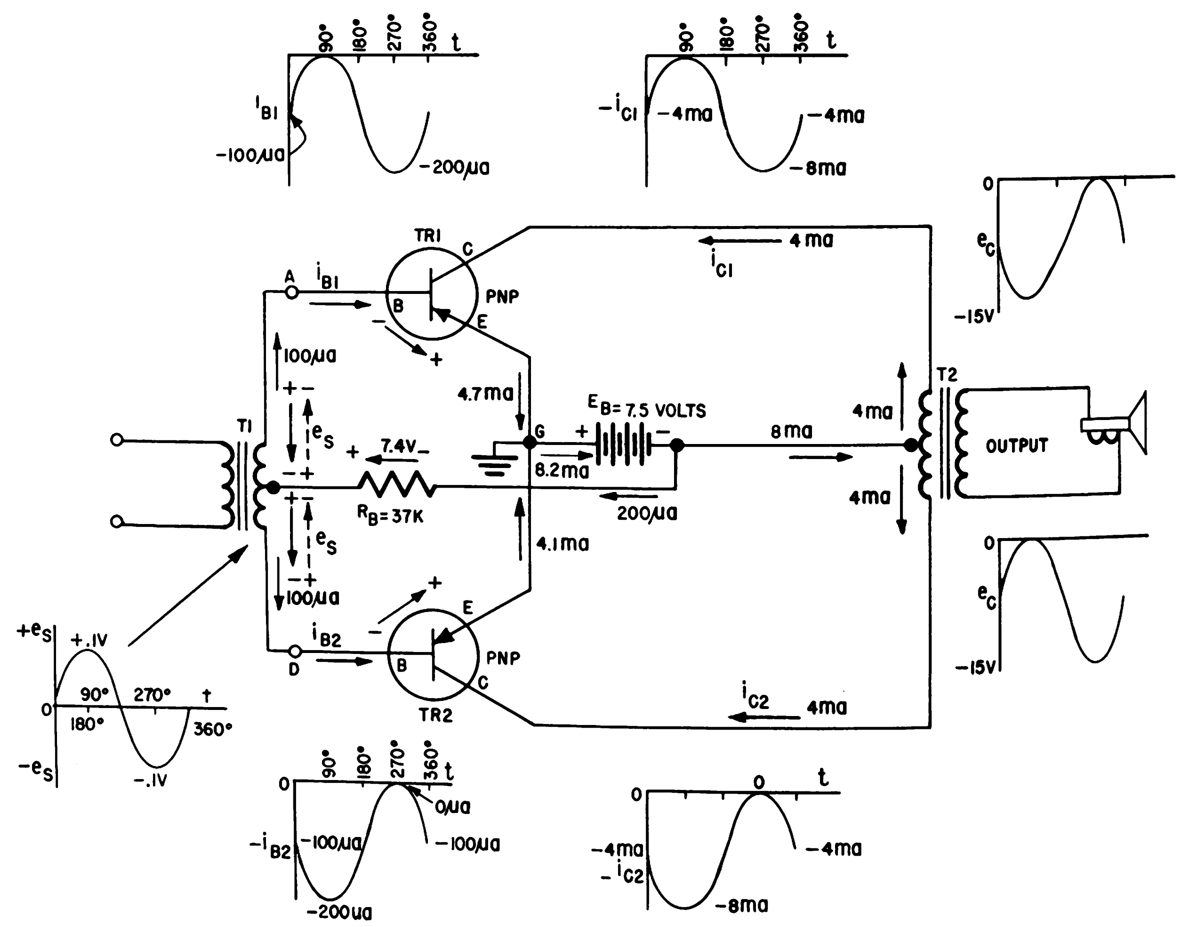
PUSH-PULL

Transistor power amplifiers are usually connected in push-pull because of the advantages over single-ended operation. The most important advantages are the reduction in distortion and the removal of d-c core saturation from the output transformer. Second harmonic distortion and other distortion caused by even-order harmonics are cancelled in push-pull class A amplifiers. The load impedance and the output power are twice the values for single-ended operation. The incremental inductance of the output transformer is higher as a result of the elimination of the d-c component of primary current.

A class A push-pull amplifier using PNP transistors is illustrated in figure 11-22(A). The characteristic curves for these transistors are illustrated in figure 11-22 (B). When biased for class A operation the no-signal collector current is 4 ma (point B on the load line). The corresponding base current is 100 μa. The voltage across the bias resistor, R_B, is the difference between the battery voltage and the drop across the base-emitter circuit, or 7.5 - 0.1 = 7.4 v. The no-signal base-emitter current through R_B is the sum of the base-emitter current supplied to each transistor, or 200 ma. The resistance of R_B is $\frac{7.4}{200 \times 10^{-6}} = 37{,}000$ ohms.

Consider the action of the input signal on the base-emitter current of each transistor. When t = 0° the input signal is 0, and the base-emitter current through R_B divides at C, flowing in opposite directions through the two halves of the secondary of T1.

When t = 90° the signal voltage has a peak value of 0.2 v, and the direction is represented by the solid arrows. The signal voltage is distributed equally between both halves of the secondary of T1 with 0.1 v acting in each half. By tracing around the input circuit of TR1, GFCABEG, the voltage equation is developed. By Kirchhoff's law of voltages, $\sum_{\text{GFCABEG}}^{\text{VOLTS}} = 0$, and the corresponding equation is 7.5 - 7.4 - 0.1 - 0 = 0. The first term of this equation represents the battery voltage, the second term represents the drop across R_B, the third term represents the signal voltage across the upper half of the secondary of T1, and the fourth term represents the drop across the base-emitter circuit of TR1. At this instant (t = 90°) the signal voltage induced in the upper half of the secondary of T1 opposes the flow of base-emitter current in TR1, and the base current of TR1 is 0.



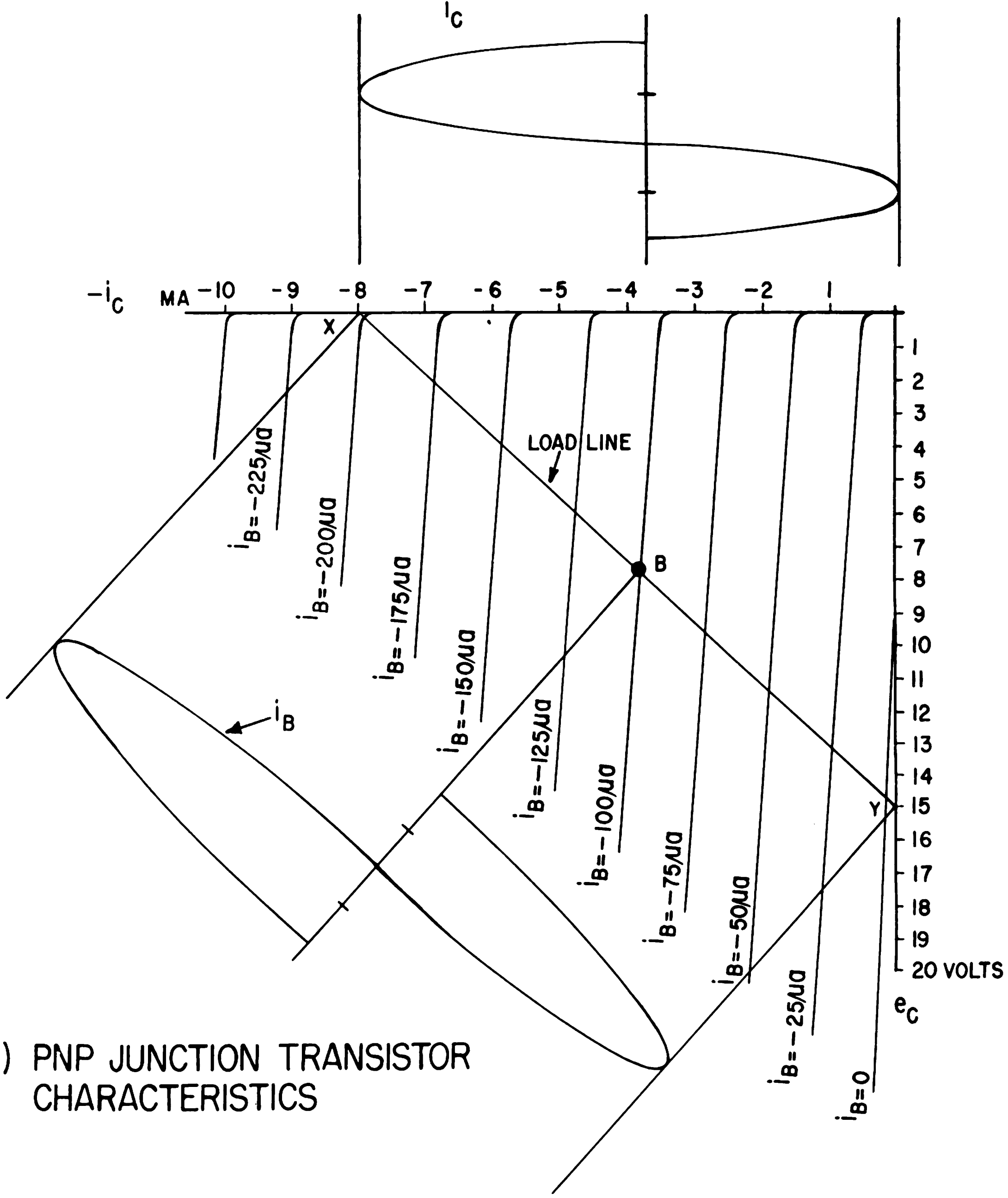
(A) CIRCUIT

Figure 11-22.—Transistor push-pull amplifier.

At the same instant the signal voltage induced in the lower half of the secondary of T1 aids the flow of base-emitter current in TR2. The voltage equation corresponding to the designation $\sum_{\text{GFCDBEG}}^{\text{VOLTS}} = 0$ is $7.5 - 7.4 + 0.1 - 0.2 = 0$. The first term represents the battery voltage, the second term represents the drop across R_B, the third term represents the voltage induced in the lower half of the secondary of T1, and the fourth term represents the drop across the base-emitter circuit of TR2. At this instant (t = 90°) the base-emitter current of TR2 is 200 μa.

One-half cycle later when t = 270° the polarities of the signal voltage are reversed as indicated by the dotted arrows in the secondary of T1. At this instant the voltage in the upper half of the secondary of T1 aids the base-emitter bias voltage of TR1, and the base current of TR1 increases to 200 μa. At the same instant the voltage in the lower half of the secondary of T1 opposes the base-emitter bias of TR2, and the base current of TR2 decreases to 0. For the upper circuit, GFCABEG $\sum_{\text{GFCABEG}}^{\text{VOLTS}} = 0$, and the voltage equation is $7.5 - 7.4 + 0.1 - 0.2 = 0$. For the lower circuit, GFCDBEG $\sum_{\text{GFCDBEG}}^{\text{VOLTS}} = 0$, and the voltage equation is $7.5 - 7.4 - 0.1 - 0 = 0$. From the fourth term in these equations the voltage drop across the base-emitter terminals of the transistors is 0.2 v. for TR1 and 0.0 v for TR2. Thus the base-emitter current of TR1 has increased to 200 μ a. while that of TR2 has decreased to 0.

The current through R_B remains constant over the input cycle, hence the voltage drop



(B) PNP JUNCTION TRANSISTOR CHARACTERISTICS

Figure 11-22.—Transistor push-pull amplifier—Continued.

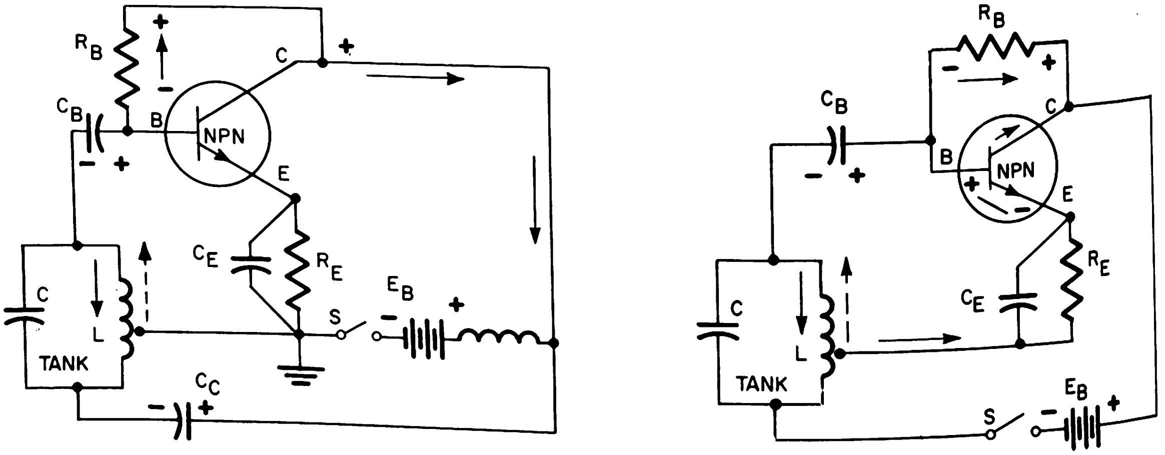
oss R_B is constant, and R_B does not re- re a bypass capacitor when the amplifier is rated class A.

The waveform of current in the collector cuits of TR1 and TR2 is like that of the input cuits. On no-signal the collector currents flow in opposite directions through the primary of T2 from the center tap. Because these currents are equal in magnitude, the ampere turns are equal. Because they are opposite in direction, they produce no effect on the magnetization of the iron, and there is no magnetization of the core when the input signal is 0. When the input signal current increases the collector current of TR2 from 4 ma to 8 ma, it decreases the collector current of TR1 from 4 ma to 0. The increasing current in the lower half of the primary of T2 and the decreasing current in the upper half combine additively in the secondary to produce the output voltage of T2. Similarly on the next half cycle the increasing current in the upper half of the primary of T2 and the decreasing current in the lower half combine additively in the secondary. The effect is the same as that of combining the output signal voltages of TR1 and TR2 in series addition across the two halves of the primary of T2. Thus, the TR1 output signal voltage of 15 v (peak to peak) combines effectively in series addition with the TR2 output signal voltage of 15 v (peak to peak) to produce a peak-to-peak output voltage of 30 v. The peak-to-peak signal current through the primary of T2 is 8 ma. Thus, the effective impedance looking into the primary of T2 is $\frac{30}{0.008} = 3750$ ohms. The power output is $e_{rms}i_{rms} = \frac{30}{2} \times 0.707 \times \frac{8}{2} \times 0.707 = 30$ mw. This value of power output is twice that of the example of figure 11-20 in which a single ended amplifier employs a transistor of the same characteristics as those of the push-pull stage.

HARTLEY OSCILLATOR

A transistor oscillator may be of the feedback type employing LC tank circuits or of the negative resistance type employing RC circuits. A transistor oscillator employing feedback with an LC tank is illustrated in figure 11-23. The oscillator is equivalent to an electron-tube oscillator of the Hartley type. The collector circuit may be shunt fed (fig. 11-23 (A)) or series fed (fig. 11-23 (B)). In this example the emitter is common to both input and output circuits. The transistors are of the NPN type. Resistor R_B limits the base-emitter bias current to the proper value. The L and C values of the tank circuit control the frequency of the oscillator. Capacitor C_B prevents the tank coil from shorting the base-emitter junction of the transistor. Resistor R_E limits the collector current to a safe value and C_E prevents negative feedback. Battery E_B provides bias current for the input and collector voltage for the output circuit.

When S is closed (fig. 11-23 (B)), collector current flows from the negative terminal of the battery through the lower portion of the tank coil to terminal E of the transistor by way of the center tap on L. The rising value of the collector current induces a voltage in the upper half of L that aids the flow of base-emitter current. The direction of this voltage is represented by the solid arrow. The accompanying increase in base-emitter current causes a further increase in collector current. The action continues until saturation is reached. Resistor R_E limits the magnitude of the collector current by causing the collector voltage to approach zero at the allowable maximum value of collector current.



(A) SHUNT FED COLLECTOR

(B) SERIES FED COLLECTOR

Figure 11-23.—NPN junction transistor Hartley oscillator.

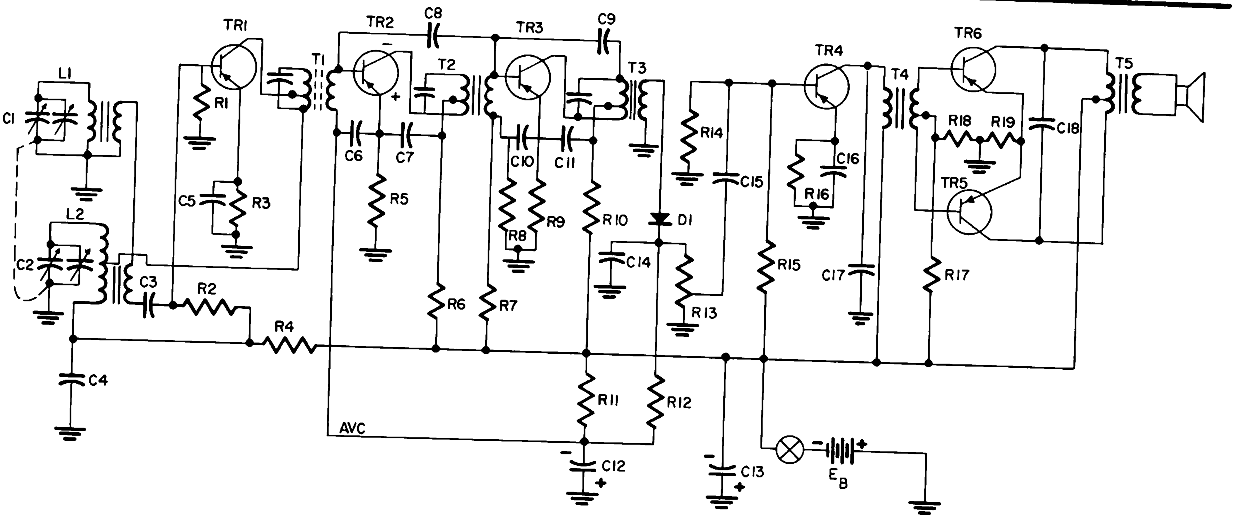


Figure 11-24.—Superhet AM radio receiver using PNP junction transistors.

At saturation the collector current stops rising and the induced voltage in the upper half f L reduces to zero. This action reduces the nagnitude of the base-emitter bias current, vhich reduces the magnitude of the collector urrent. The collapse of collector current in-uces a voltage in the upper half of L of opposite olarity to that originally induced by the rise of ollector current. The direction is indicated by ne dotted arrow. This voltage opposes the ase-emitter bias current and reduces the ollector current to zero. When the collector urrent is zero, the induced voltage in the pper half of L becomes zero and the emitter ase bias current again increases. The increase collector current initiates the second cycle operation. During each half cycle the tank apacitor charges and discharges with an inter-ange of energy occurring between the coil and e capacitor. This action controls the oscillator equency. Increasing L or C decreases the fre-ency.

SUPERHET AM RADIO RECEIVER

A superhet AM radio receiver employing P junction transistor triodes with the emitters nmon to input and output circuits is illustrated figure 11-24. The RF signal is developed oss the primary of L1 (tuned loop antenna). ansistor TR1 serves as local oscillator and xer. The secondary of L2 is the local illator feedback coil, which also acts in series with the RF signal from L1. The RF signal and the local oscillator signal act in series across the base-emitter input circuit shunted by R1. Because the base-emitter circuit is a rectifier, it acts as a nonlinear impedance. Therefore the sum and difference frequencies of the RF signal and the local oscillator appear across the input in addition to the RF signal and the local oscillator voltage.

The primary of T1 is resonant to the IF (the difference frequency), and the other three frequencies are of insufficient strength to get through T1. Tuning capacitor C1 is resonant with L1 over the broadcast band. Tuning capacitor C2 is ganged with C1 and is resonant with L2 over a range of frequencies above the RF input by an amount equal to the IF. Capacitor C3 blocks the battery voltage from the secondaries of L1 and L2 and couples the RF signal and local oscillator voltages to the input circuit of TR1. Resistor R3 limits the collector current to the proper value, and C5 prevents degeneration from occurring across R3. Resistor R2 provides the proper base current bias for TR1. The parallel resonant tank of T1 is tapped down for a proper impedance match with respect to the collector circuit of TR1. Resistor R4 and capacitor C13 act as a decoupling filter for L2 with respect to the other stages and the common battery supply. Capacitor C4 couples the lower end of L2 to the corresponding end of C2 and thus completes the L2-C2 tank circuit without grounding the negative terminal of the battery.

Transistor stages TR2 and TR3 are IF voltage amplifiers employing IF transformers (T2 and T3) with tuned primaries and untuned secondaries. The primaries are tapped down for the proper impedance match, and the secondaries are untuned because they supply low impedance loads. The transistors have internal capacitance between base and collector circuits, which corresponds to the interelectrode capacitance between plate and control grid in triode electron tubes. Capacitors C8 and C9 neutralize the TR2 and TR3 stages respectively. Neutralization prevents positive feedback through the internal capacitance coupling and also permits the primaries of T2 and T3 to be independently alined without interaction.

The first IF amplifier has an a-v-c voltage acting in the base-emitter circuit derived from C12. The voltage across C12 is obtained from the output of the second detector, D1, through decoupling resistor R12. The magnitude of the d-c voltage across C12 depends upon the amplitude of the audio voltage component developed across R13, which depends, in turn, upon the strength of the IF signal across the secondary of T3. The action on the increased signal increases the base-emitter bias current and shifts the operating point of TR2 from B toward point X on the load line (fig. 11-22 (B)). A portion of the collector-current signal component is clipped, and a corresponding reduction in input signal energy is delivered to TR3. The flywheel effect in the T2 primary-tuned circuit supplies the missing portion of the clipped signal. However with limited energy content the amplitude of the output signal is limited and a-v-c action is obtained.

The IF component of the output signal of T3 is by-passed around R13 to ground by way of the demodulation capacitor, C14. The audio and d-c components of the output signal are developed across diode load resistor R13. The audio component is coupled to the input circuit of the audio voltage amplifier, TR4, through C15, which blocks the d-c component of R13 from the input circuit of TR4 and also blocks the battery voltage from the diode detector, D1. Transformer T4 couples the output signal of TR4 to the input circuits of the final amplifier. This stage consists of transistors TR5 and TR6 connected in push pull. Phase inversion of the input signal to the push pull stage is obtained by connecting the bases of TR5 and TR6 to opposite ends of the TR4 secondary and returning the emitters to the center tap. The voltage divider R17-18 provides the proper base-emitter bias for class B operation. Resistor R19 limits the collector currents to the safe value for maximum signal and maximum temperature conditions. The audio amplifiers do not require neutralizing because of low-capacity coupling between collector and base at the audio frequencies.

SERVICING TECHNIQUES

Transistors may be damaged beyond repair by applying the incorrect polarity to the collector circuit or excessive voltage to the input circuit or by careless soldering techniques that overheat the transistor. Also the low-voltage electrolytic capacitors used in transistor circuits are easily damaged by reversed polarity connections or excessive voltage.

Because of the small physical size of transistors and their associated circuit components, small sized tools should be used. Small cutting pliers and needle-nose pliers are more useful than the conventional sizes. Narrow-blade screw drivers are more useful than larger, conventional types. A sharp-pointed, thin metal probe is also useful for cleaning solder from small openings or areas. Soldering is performed more satisfactorily with a small low-wattage soldering iron or pencil having a narrow point or wedge.

Always ground the frame of the soldering iron to the chassis when soldering around transistors of transistor circuitry. Enough leakage voltage is present in most irons to cause damage to the transistor. Soldering with an ungrounded iron to a transistor and its associated circuitry held in one's hand may damage the transistor because the body has considerable capacitance to ground; the charging of this capacitance through the transistor can cause permanent damage to it. The junction is made very thin in order to operate at very high frequencies and is easily damaged by excessive current. The same precaution (grounding the frame or chassis) should be followed in applying any a-c operated test equipment.

When soldering transistor leads, the terminal lead should be held with needle-nose pliers positioned between the transistor body and the lead end. This arrangement allows the heat to travel into the pliers, thereby diverting it away from the transistor. To make sure that all the heat is drawn away from the transistor, the pliers should remain securely on the lead for a short interval after removing the iron. Transistor leads should be relatively long and the soldering operation should be as short as possible. Low-temperature rosin core solder is the proper type to use.

Where transistor leads are stiff they may be plugged into appropriate type sockets. In this case the socket terminals should be soldered only when the transistor is out of the socket.

Transistors are biased in the forward, or low-resistance direction, of the base-emitter input circuits. These circuits are particularly vulnerable to any excess voltage over their rated value. This excess voltage can cause a current to flow that will overheat the transistor junction and permanently damage it. Proper operation depends on the crystal lattice structure and the impurity atoms that are present. Heat will distort the lattice and affect the behavior of the impurity atoms so that normal transistor action is seriously impaired. Excessive collector current will generate more heat in the relatively high impedance of the collector circuit and damage the transistor. Maximum allowable collector current depends on the ambient temperature. If the ambient temperature goes up, the maximum allowable collector current is decreased.

Both the value and the polarity of voltages to be applied to transistor circuits should be carefully checked before they are applied. It is important to know the type of transistor being used. The NPN types require positive collector voltages and negative emitter voltages (fig. 11-19); whereas, the PNP type requires negative collector voltages and positive emitter voltages (fig. 11-20). Transistors should be inserted properly in their sockets before voltages are applied in order to avoid the possibility of transient current which might damage a transistor if allowed to flow. Similarly, voltages should be disconnected before removing transistors from their sockets. If the magnitude of the collector current is in doubt, a milliammeter of suitable range should be connected in series with the collector terminal and battery potential should be applied gradually, for example, by means of a potentiometer.

When signal generators are used in testing ransistor circuits the magnitude of the signal should be limited to a low value, especially in he low-level input stages. Indirect coupling, either capacitive or inductive) is preferred to irect coupling. The ungrounded lead from he output terminal of the signal generator can be terminated on the insulated portion of a capacitor or resistor in the circuit under test. Another method is to connect a coil to the output terminals of the signal generator and bring the coil into proximity with inductive elements of the circuit under test.

If an ohmmeter is used to check components in a transistor circuit, the range in use should not employ a battery of more than about 3 v. Higher voltages can damage the transistor. Electrolytic capacitors may give incorrect readings if the rule for polarities of the ohmmeter leads is not observed when connecting the leads to the capacitor terminals. The positive lead of the ohmmeter must connect to the positive terminal of the electrolytic capacitor.

A transistor may be tested for its amplifying property by inserting it in a circuit like that of figure 11-19 and applying a suitable input signal, preferably from an audio signal generator. The input and output voltages are then measured with a vacuum-tube voltmeter and the gain is calculated. This value is then compared with that of a transistor known to be in good condition.

When the output of a transistor radio receiver is distorted or weak, the first thing to check is the battery. Its voltage should be checked with a vacuum-tube voltmeter or high resistance volt-ohmmeter while the set is turned on. If the battery is weak, its voltage will be down 20 percent or more. Before replacing the battery the resistance between the battery clips should be checked. For example, if the resistance measured with an ohmmeter, (requiring a battery of not over 3 v.) is 8,000 ohms and the manufacturer's limits are 6,000 to 15,000 ohms, it is safe to insert a new battery. An alternative method of some manufacturers is to indicate the allowable current drain of the battery instead of the resistance between the battery clip with the battery removed. To obtain an indication of the current that the battery supplies to the set a milliammeter can be connected in series with the battery and either clip.

TRANSISTOR POWER SUPPLIES

Transistor circuits require relatively low amounts of power compared to electron-tube circuits, and for this reason, small batteries like the carbon-zinc types and the newer mercury types are used.

The mercury cell employs a negative electrode of zinc and a positive electrode of mercuric oxide. The electrolyte is a solution of potassium hydroxide. Local action is very small and the cell has a long shelf life.

The range of transistor power supply ratings is from the low voltage and current ratings of small flashlight cells to the medium ratings of 15-volt to 30-volt "B" batteries. The smaller voltage and current requirements pertain to subminiaturized equipments like hearing aids. The medium requirements pertain to transistor power amplifiers like those terminating in a loudspeaker.

Where transistor circuits are to be operated from an a-c source, the transistor power supply utilizes components that are smaller than those used in electron-tube power supplies. The components may include a 2-winding power supply transformer, a crystal rectifier, a voltage divider, and a low pass filter. The filter components may include resistors and electrolytic capacitors. To prevent damage to transistors due to excessive current, series limiting resistors are sometimes provided.

INTERCOMMUNICATION SYSTEM

Figure 11-25 shows the amplifier and voltage regulator used in the control boxes of the ICS system in the A3D aircraft. Each control box contains these two units, along with switching arrangements for the multitude of circuits with which it works.

Inputs to the amplifier are radio, ICS, and microphone. Switching arrangements to connect the various inputs into the amplifier are not shown. B and C are jumpered to place the microphone at the input to Q3, and K and C are jumpered to place the receiver at Q3's input. The ICS input is capacity coupled to the amplifier at all times. Q3 is the driver for the push-pull amplifiers Q4 and Q5, and the audio output is applied to pin D.

Radio and ICS signals may be applied to the amplifier simultaneously; however, the AVC stage Q1 receives part of the ICS signal and develops a bias voltage for the buffer stage Q2. When the radio and ICS signals are applied simultaneously, the buffer is biased so as to attenuate the radio signal. When the radio signal alone is applied, it is jumpered from pin K to pin C and receives the same treatment as the ICS signal.

Stabilization feedback is supplied from pin D to the output of the driver by RC coupling. The amplifier uses a regulated 20 volts d. c. from the voltage regulator, shown at the bottom of the figure.

ZENER DIODE

The Zener diode, commonly called a breakdown diode, is a welcome newcomer to electronics. Its principal uses are voltage regulation, surge protection, arc suppression, coupling, biasing, and switching.

Zener diodes are available over a wide range of voltage and power levels, as compared to the VR tube which is limited in these respects. A comparison between the two will be made later. It is unique among semiconductors in that its rectifying junction operates at a reverse bias condition. Special diffusion techniques are applied in the formation of the junction to create the required reverse bias properties. When this rectifying junction is back-biased above the junction breakdown voltage, the Zener knee and constant voltage plateau that characterize the Zener operating curve are obtained.

In the forward-biased diode (fig. 11-26 (A)), the P region is made more positive than the N region. This polarity causes the holes in the P region and the electrons in the N region to be pressed against the potential barrier, thereby decreasing the barrier's width and lowering its resistance. When the PN junction is reverse biased, figure 11-26 (B), the positive holes (P material) and the free electrons (N material) are attracted away from the potential barrier. This increases its effective width and increases its resistance to current flow.

Semiconductor materials are never perfect. There are always a few free electrons in the P material and a few free holes in the N material. Thermal agitation will produce even more free electrons and holes, which are minor current carriers. These cause a small current to flow in the back-biased condition. This extremely small current is called reverse current, and tends to remain at an almost constant value at all voltages up to the junction breakdown voltage.

As the reverse voltage is increased to this critical point and beyond (fig. 11-27), current conduction across the potential barrier increases very rapidly. The transition from nonconduction to conduction is very sharp and

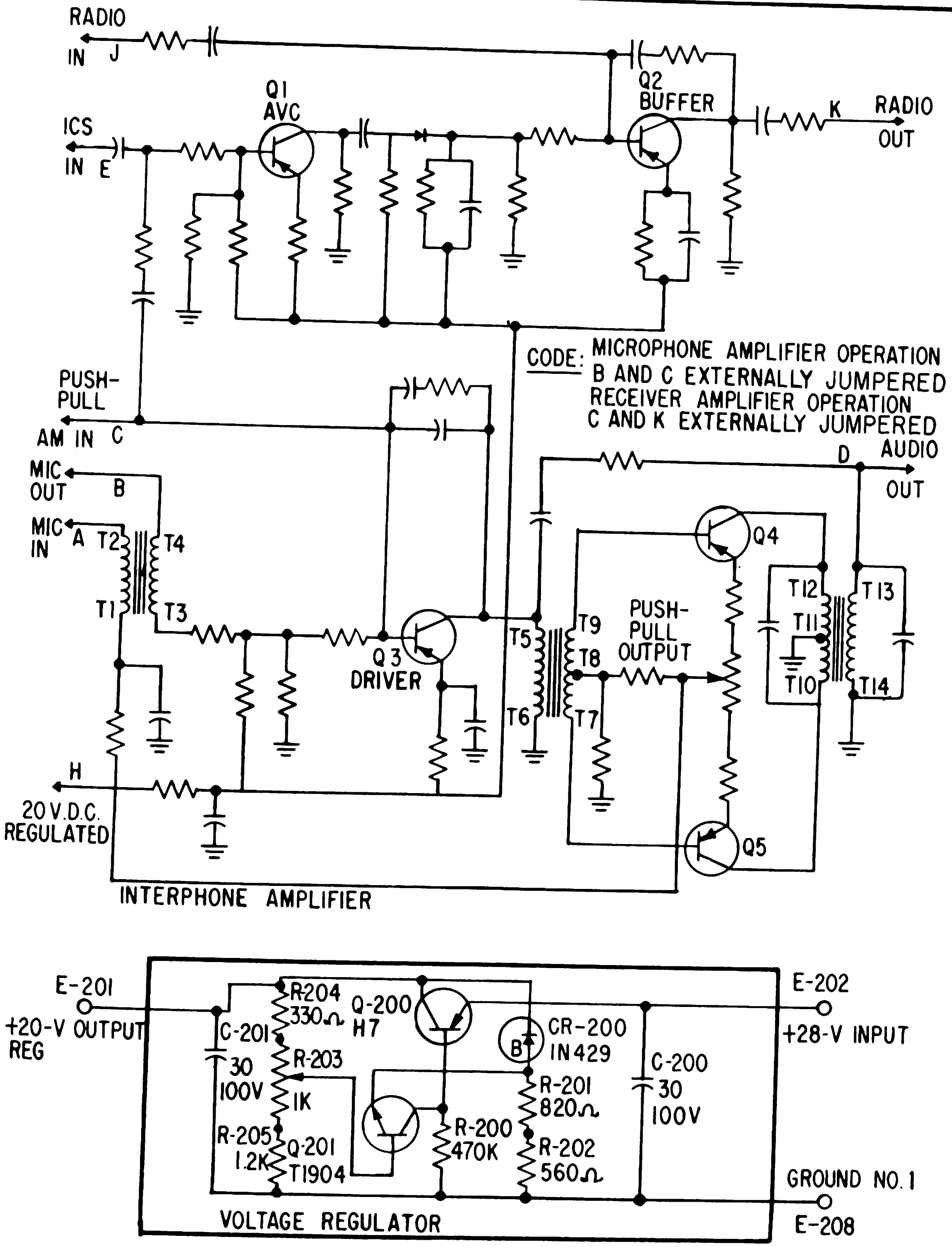
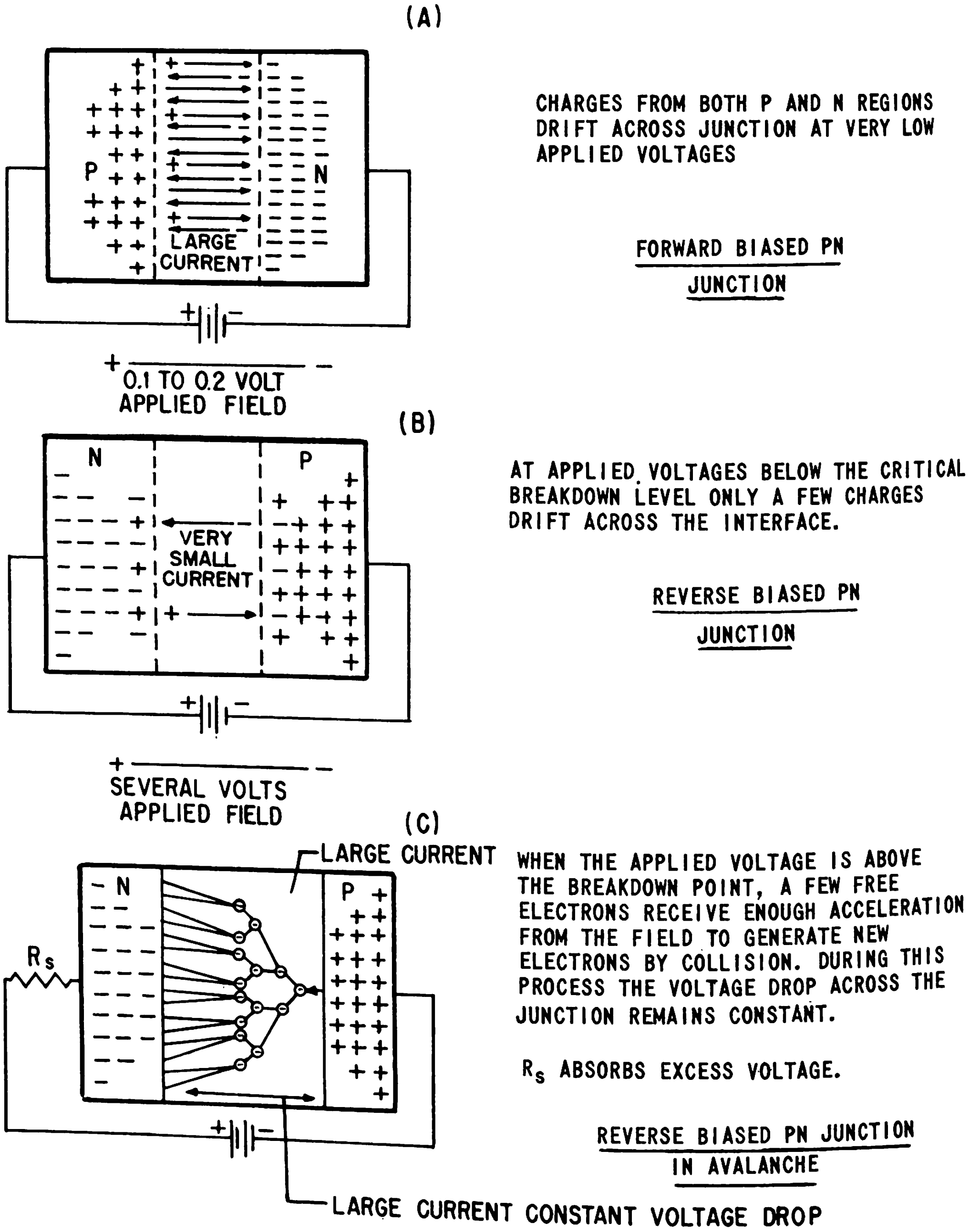


Figure 11-25.—Amplifier and voltage regulator.

l defined in a Zener diode. This point on the racteristic curve is called the Zener Knee. At applied voltages greater than the break- n point, the voltage drop across the diode junction becomes essentially constant for a wide range of currents. This is the Zener control region. The reverse conductance and nearly constant voltage drop are the results of an



CHARGES FROM BOTH P AND N REGIONS DRIFT ACROSS JUNCTION AT VERY LOW APPLIED VOLTAGES

FORWARD BIASED PN JUNCTION

AT APPLIED VOLTAGES BELOW THE CRITICAL BREAKDOWN LEVEL ONLY A FEW CHARGES DRIFT ACROSS THE INTERFACE.

REVERSE BIASED PN JUNCTION

WHEN THE APPLIED VOLTAGE IS ABOVE THE BREAKDOWN POINT, A FEW FREE ELECTRONS RECEIVE ENOUGH ACCELERATION FROM THE FIELD TO GENERATE NEW ELECTRONS BY COLLISION. DURING THIS PROCESS THE VOLTAGE DROP ACROSS THE JUNCTION REMAINS CONSTANT.

R_s ABSORBS EXCESS VOLTAGE.

REVERSE BIASED PN JUNCTION IN AVALANCHE

Figure 11-26.—Zener diode current characteristics.

avalanche current multiplication in the potential barrier.

The avalanche, in simple terms, can be thought of as a process of electron multiplication by collision. A schematic representation of this process is shown in figure 11-26 (C). In this process, a free electron in the P material receives enough energy from the applied field across the potential barrier to accelerate it sufficiently so that when it collides with a fixed electron it can knock it free. This pair of electrons is again accelerated until each collides with two more electrons, resulting in four electrons which are accelerated, and so on. This current multiplication process can grow at higher and higher applied voltages. However, the

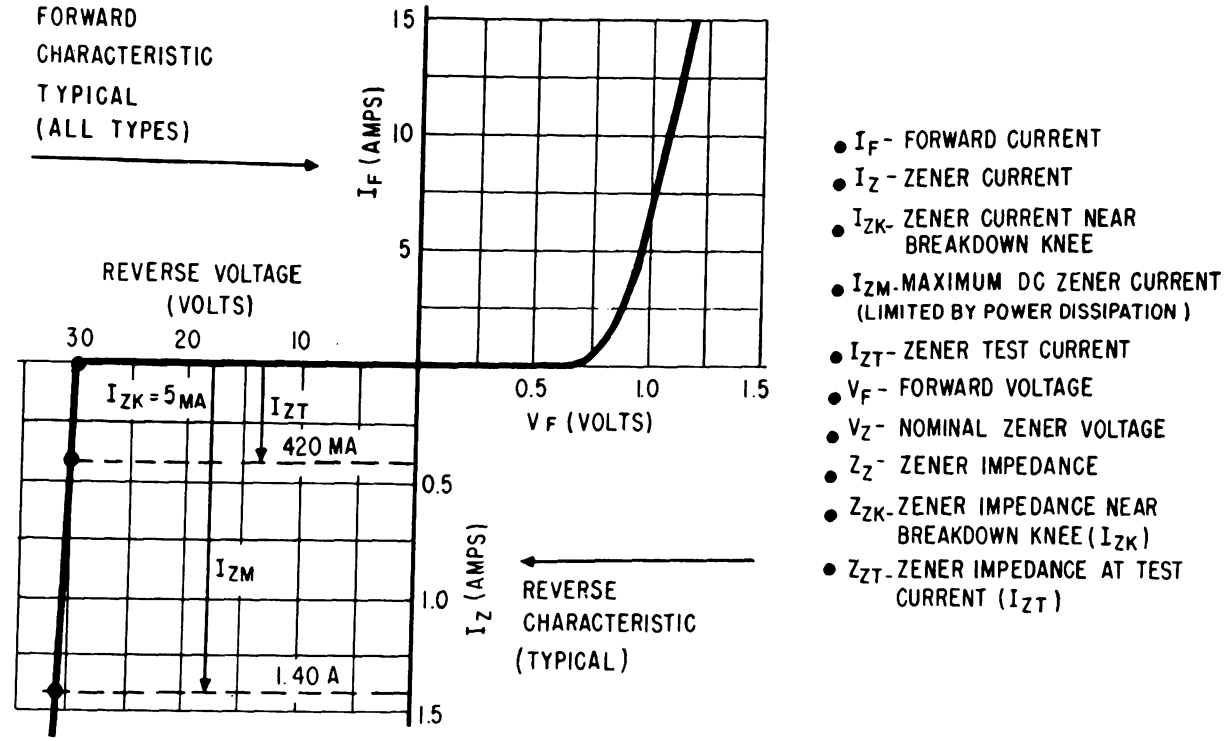


Figure 11-27.—Zener characteristic curve.

ltage across the barrier does not increase bstantially, since the energy of the avalanche ectrons is limited by the critical impact locity.

This constant voltage condition across the ode junction implies that there must be a sistive element somewhere in the circuit ross which the applied voltage can drop to the nstant level. This ballast element may be a ssive resistance element (resistor), an active sistance element (transistor), a capacitive ctance (capacitor), or an inductive reactance.

The voltage level at which breakdown occurs losely controlled by the impurity concentra- ns and gradients introduced into the semi- ductor material. The special semiconductor usion techniques insure a very close control his important Zener diode parameter, as well he associated limits and tolerances.

Figure 11-27 is typical for all types of er diodes. It shows that the Zener diode can duct current in both directions. The forward rent, I_F, is a function of forward voltage, V_F. s is essentially the same for all Zener diodes. forward characteristics are used in some ications. V_Z ,is the nominal Zener voltage which may range from 6.8 to 200 volts, depending on the type of diode. The Zener knee is represented by a sharp break from virtual nonconduction to conductance at the nominal Zener voltage, V_Z. The minimum regulator current varies in various types. The maximum Zener current, I_{ZM}, is limited by the power dissipation of the diode. Between the limits of I_{ZK} and I_{ZM}, which are 5 ma. and 1,400 ma. (1.4 amps) in the example of figure 11-27, the Zener voltage, V_Z, is essentially constant. The precise value of V_Z will change slightly due to temperature.

Voltage Regulation

Voltage regulation is required in many applications to correct for two kinds of circuit variables. These are (1) variations in input voltage level, and (2) variations in circuit load. Load variations may be due to its normal operation during which the load voltage is to remain constant.

Figure 11-28 compares the Zener diode as a voltage regulator, with the familiar gaseous tube regulator. The VR tube requires a supply

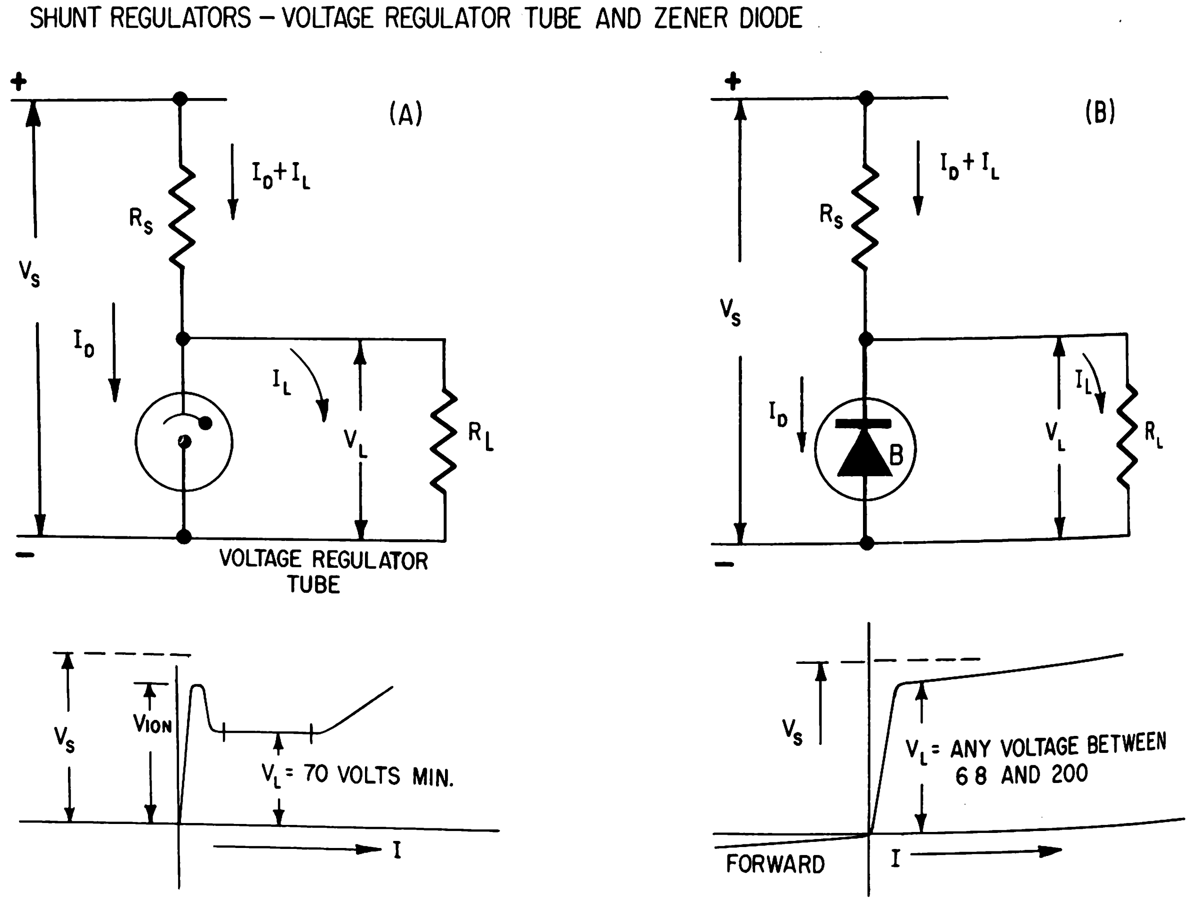


Figure 11-28.—Zener diode versus VR tube.

voltage as much as 20 percent higher than its regulated output voltage; while the Zener diode breaks down, or conducts, at its specified voltage. Circuit operation of the two regulators is otherwise almost identical; however, the differences in physical and electrical characteristics point out the benefits of the Zener diode over the VR tube.

The gaseous regulator tube volt-ampere characteristics are established by the design and construction of the tube. The voltage level V_L is a function of the gas discharge characteristics established by the kind of gas used. As a consequence, the minimum voltage level which can be obtained is about 70 volts. These tubes are not ordinarily available over a small-change range of voltages, but vary in large jumps, such as 70, 90, 105, 135 volts, and so forth.

Zener diodes are not bound by these limitations. They are available over a continuous voltage range in 5, 10, or 20 percent tolerance intervals from a minimum of 6.8 volts to a maximum of 200 volts.

In the VR tube, the constant voltage plateau is narrowly limited between two current quantities determined by the positions of the tube elements. Exceeding the maximum current limitation of the VR tube results in a higher voltage drop, a loss of regulation, and eventual destruction of the tube. In the Zener diode the maximum current carrying capacity is limited only by the junction characteristics and the diode's ability to dissipate heat. These considerations make possible the production of Zener diodes over a wide range of power handling capabilities. In addition to the advantages of regulated output at almost any desired voltage level, Zener diodes have the added advantages of small physical size, extreme ruggedness, and extra filtering action.

Zener Symbol

The Zener diode is normally used with reerse bias applied, and its operating characterstics require that current flow be in the oposite direction from other solid-state diodes. herefore, the symbol for the Zener diode indicates current flow WITH the arrow, and is identified (in this chapter) by a small B beside the symbol (fig. 11-28). The B indicates Zener or breakdown diode. No standard symbol has been established for the Zener diode as yet, but in schematics it will normally appear different in some respect from other diodes.

QUIZ

1. Adding arsenic to germanium crystals in small quantities
   a. creates hole carriers
   b. strengthens the crystal structure
   c. increases the conductivity of the crystals
   d. decreases the conductivity of the crystals

The primary advantage in using a grounded-collector amplifier is its application for
   a. power amplification
   b. impedance matching and isolation
   c. high voltage gain
   d. phase inversion

To which vacuum-tube amplifier circuit does the grounded-emitter amplifier compare?
   a. Grounded grid
   b. Cathode follower
   c. Grounded plate
   d. Grounded cathode

Applying a voltage across a PN junction in the forward direction
   a. increases the junction resistance
   b. blocks current flow
   c. increases the potential hill
   d. lowers the potential hill

In a transistor amplifier, if the signal causes an increase in base current the
   a. collector current increases
   b. emitter current decreases
   c. collector current decreases
   d. output signal is positive-going

The biggest factor in the increased efficiency of the transistor over the vacuum tube is the
   a. relatively small potentials involved
   b. elimination of filament power
   c. use of current for bias
   d. method of biasing

7. In the point-contact transistor, the
   a. emitter is biased in the high resistance direction
   b. collector is forward biased for low resistance
   c. emitter is biased forward and the collector is biased in reverse
   d. collector is biased forward and the emitter is biased in reverse

8. The relationship of input and output resistance of the grounded collector amplifier is
   a. high input; high output
   b. low input; high output
   c. high input; low output
   d. low input; low output

9. One great difference between junction and point-contact transistors is the
   a. current gain, emitter to collector (alpha)
   b. method of d-c biasing
   c. type of crystal used
   d. type of material used

10. The grounded-emitter amplifier has the capability of having the highest
   a. current gain
   b. power gain
   c. resistance gain
   d. voltage gain

11. The basic difference between vacuum tube and transistor circuits is the
   a. method of d-c biasing, and component values
   b. class of operation
   c. type of coupling between stages
   d. types of filament power employed

12. The current gain (alpha) of a junction transistor is less than 1 because
   a. the collector junction possesses a large barrier
   b. base current is greater than emitter current
   c. electrons diffuse at a slower rate than holes
   d. recombination base current varies with the emitter current

13. The Zener potential of a PN junction is the point of
    a. forward conduction saturation
    b. zero bias
    c. reverse breakdown
    d. diode destruction

14. The difference between the circuitry of PNP and NPN transistors is the
    a. position of the load resistor
    b. point where the signal is injected
    c. polarity of the bias batteries
    d. number of bias batteries required

15. One disadvantage in stabilizing transistor amplifiers is that stabilization
    a. increases signal distortion
    b. causes regeneration of the input signal
    c. increases the effective gain of the amplifier
    d. reduces the effective gain of the amplifier

16. A grounded-base amplifier is characterized by a
    a. very low input resistance and a high output resistance
    b. medium input resistance and a medium output resistance
    c. high input resistance and a very low output resistance
    d. medium input resistance and a high output resistance

17. In semiconductor crystals, a hole carrier is formed when
    a. a positively charged atom becomes mobile
    b. a valence electron moves to an acceptor site
    c. an electron vacates the crystal, causing an unbalance of charges
    d. arsenic is added to N material

18. A characteristic of the grounded-collector amplifier is a
    a. voltage gain less than 1
    b. power gain less than 1
    c. current gain less than 1
    d. high voltage gain

19. The Zener diode is generally employed as a
    a. detector in receivers
    b. power rectifier
    c. voltage regulation diode
    d. clamper

20. Stability of operation of most transistor amplifiers is temperature dependent. As the temperature increases the
    a. average collector current decreases
    b. conducting resistance increases
    c. collector voltage increases
    d. average collector current increases

21. In the grounded-base NPN transistor amplifier, a positive-going input signal results in
    a. an increase in emitter current
    b. a positive-going signal at the collector
    c. a polarity reversal of the signal, input to output
    d. an increase in collector current

22. The grounded-emitter amplifier has a
    a. low input and a high output resistance
    b. medium input and a medium output resistance
    c. high input and a low output resistance
    d. medium input and a high output resistance

23. In the grounded-emitter amplifier,
    a. the current gain is less than 1
    b. the emitter is reverse biased
    c. a polarity inversion occurs, input to output
    d. there is no polarity inversion

24. PN junction diodes and transistors are
    a. alternate layers of P-type and N-type material in the same piece of semiconductor crystal
    b. P-type and N-type crystals in electromechanical contact
    c. alternate layers of P-type and N-type crystals joined mechanically, thus creating high barrier forces
    d. P-type and N-type material separated by an impurity

25. Amplification by a transistor is principally due to its
    a. applied voltage being small
    b. relatively high resistance gain
    c. low conduction resistance
    d. low power dissipation

CHAPTER 12

PRINCIPLES OF TELEVISION

INTRODUCTION TO TELEVISION

An introduction to television is given in *AT 3 & 2*, NavPers 10317-A. Since most of the material covered in that course will not be repeated, you are advised to review that material before continuing with this one. In doing this you will gain a continuity of instruction that presents TV theory in a logical and simple manner. An understanding of the composite TV signal and the functional block diagram of a TV system are essential to the reader. These are presented in *AT 3 & 2*.

The approach in this chapter is generalized, and specific equipments are treated only to the extent necessary to clarify the operating principles of certain specialized circuits. As is true of many other seemingly complex electronic equipments, television is not actually as complex as it might appear to be when the overall operation is considered. However, the basic simplicity becomes apparent only when the system is reduced to its individual components and the function of these components is considered separately.

Although the operation of the individual components is relatively simple, television is a comprehensive subject. Much of the theory covered in *Basic Electricity*, NavPers 10086-A, and *Basic Electronics*, NavPers 10087, plus some of the theory of specialized circuits covered in the rating courses is utilized in explainng the operation of television circuits. Thus, he study of television affords an admirable review of the basic principles of electricity and lectronics and at the same time familiarizes he technician with an important new branch of ommunication. Throughout this chapter it is ssumed, of course, that the reader has a horough knowledge of the basic principles of lectricity and electronics.

It must be borne in mind that in a single hapter it is hardly possible to give a detailed treatment of all the various ways a specific job in a television receiver may be accomplished. For example, there are numerous methods of controlling the horizontal sweep oscillator in a television receiver. There are also various methods used in clipping, clamping, and filtering; and likewise there are variations in the type of circuits used in automatic-gain-control, automatic-frequency-control, and high-voltage circuits. In general, only the simple more straightforward circuits that will convey the basic concepts are used.

Most probably, naval aircraft will soon be using TV for many purposes, but TV in naval aircraft is presently limited to closed-circuit applications. Several aircraft carriers employ closed-circuit TV to such advantage that it is certain to become general practice on many ships. Projects involving airborne TV, and TV relaying, have been highly successful. A closed-circuit system for disseminating weather information to remote points has been used for several years. TV is definitely here to stay until something better replaces it.

For purposes of continuity, a small portion of the material in *AT 3 & 2* will be repeated. This material will also be covered in more detail to give a more comprehensive study at the AT 1 and C level.

Scanning

As was explained in *AT 3 & 2*, the television image (or the electrical impulses that are the equivalent of the image) is transmitted element by element in quick succession. In the present state of the art, any other method of transmission would be too complex and expensive. Fortunately, it is possible to transmit and reconstruct the image in this manner and still maintain good picture quality provided the number of picture elements transmitted and reproduced remains large.

In order to transmit the image impulses element by element, it is necessary to employ a system of scanning; that is, the image is swept by an electron beam in a systematic manner so that during a given period of time all parts of the image are covered, or swept, by the electron beam. Likewise, in the receiver, where the image is reconstructed, a similar system of scanning is employed.

In the iconoscope, scanning is accomplished in the following manner. The electron beam of small diameter is formed and given the desired velocity by the electron gun located in the neck of the tube (fig. 12-1 (A)). Deflection of the electron beam across the mosaic is accomplished by the deflection coils that are positioned around the neck of the tube.

A simplified illustration of scanning in the iconoscope camera tube is shown in figure 12-1 (B). The electron beam begins its scan at the upper left-hand corner of the mosaic and moves horizontally (in this example) along line 1 toward the right. The globules shown in the illustration are exaggerated in size in order to simplify the illustration. All of the globules in line 1 are in the bright part of the mosaic. Therefore, they have lost the same number of electrons and have accumulated uniform positive charges. As the beam sweeps across these globules, the charges are neutralized, and a relatively steady current flows from the metal coating of the mosaic plate down through R in figure 12-1 (A) returning through the B supply to the electron beam and back to the associated globules. The same situation prevails while line 2 is being scanned.

A portion of the image (one rectangle within another) is located in line 3, and there will not be a steady flow of current through R as the beam traverses this line. The flow is steady until the fourth globule is reached. From four through thirteen the globules have been charged only slightly, and this discharge current through R is slight when the beam sweeps across them. Beginning with number fourteen, the output current increases again. The same reasoning may be applied to lines 4 and 5. The relative strengths of the signal currents are shown at the bottom of the figure.

If the globules are extremely small and close together, and the image has great detail, there will be many changes in current during the course of a single scan. (It is assumed that the cross-sectional area of the electron beam is small.) The flow of these tiny pulses of current down through R develops signal voltages at the input of the amplifier tube. In order that all of these signal voltages may be passed through the amplifier (as well as through others in the transmitter and the receiver), it must be capable of passing a wide band of frequencies.

Band-Pass Requirements

Some idea of the band-pass requirements may be gained from the following considerations. For simplicity, it is assumed that each line to be scanned contains 1,000 globules, each insulated from the others; it is assumed also that the diameter of the electron beam is approximately that of a globule and that each adjacent globule has a different charge.

According to the standards employed in the United States, 525 lines are scanned by the electron beam in tracing over the entire mosaic on which the image is formed. As will be pointed out later, some of these lines are lost during the retrace time. The mosaic is completely scanned 30 times in one second. Therefore, the number of lines scanned in one second is

$$525 \times 30 = 15{,}750;$$

this is known as the HORIZONTAL SWEEP FREQUENCY.

The number of globules (each having a charge equivalent to a picture element) contained in one line is assumed to be 1,000, but in actual practice it is considerably less. The number of elements in the image is

$$15{,}750 \times 1{,}000 = 15{,}750{,}000.$$

If a complete cycle is assumed to be the change in signal voltage developed when the beam passes across two successive globules, then the frequency is

$$\frac{15{,}750{,}000}{2} = 7{,}875{,}000 \text{ c.p.s.}$$

In order to reproduce all of the picture elements perfectly, the transmitter and receiver circuits must be able to pass, without distortion, a band of frequencies approximately 7.87 mc. wide.

In practice, it is not necessary to pass a band of frequencies this wide. There are less than 1,000 picture elements per line, and each globule of the light-sensitive compound may not

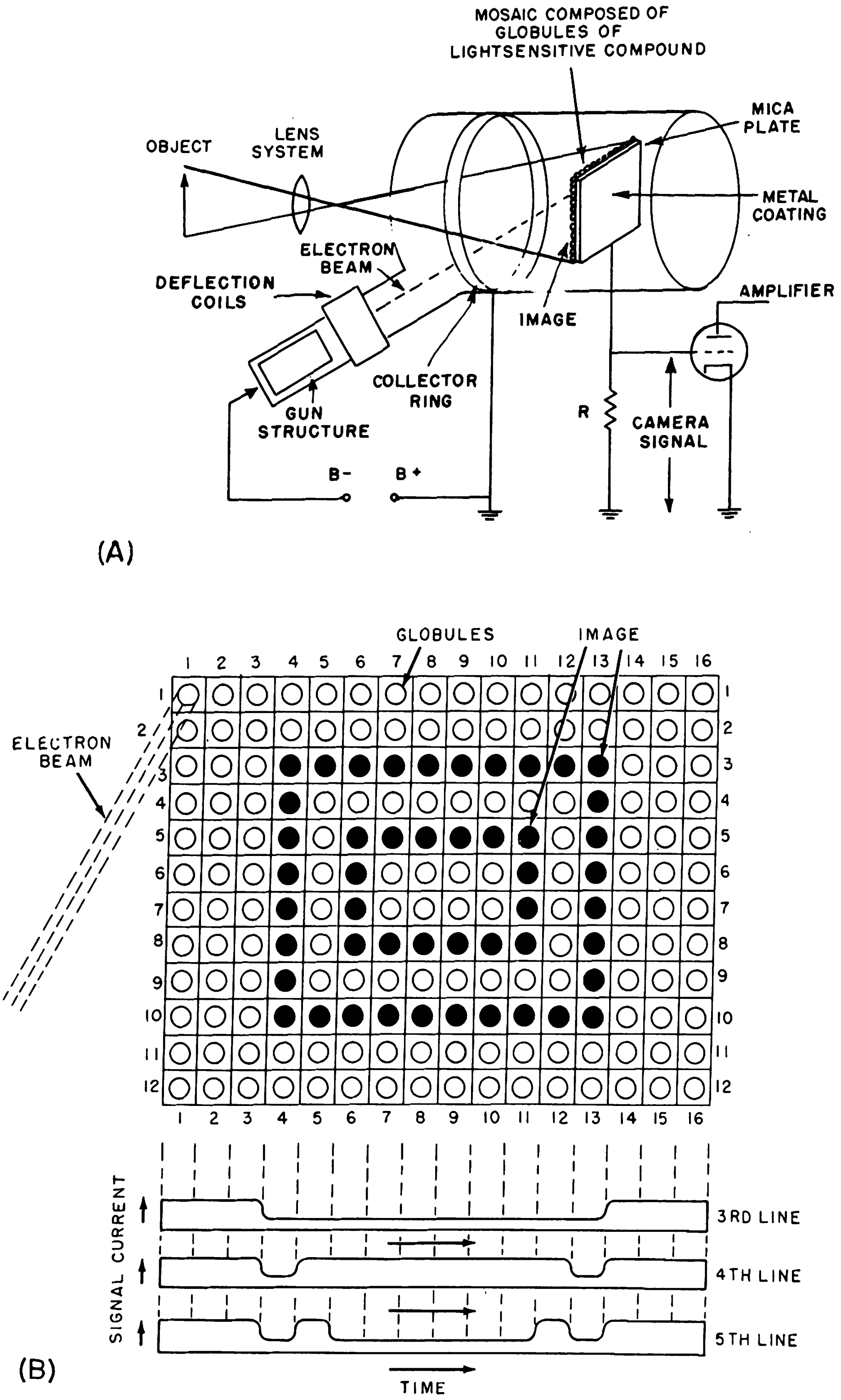


Figure 12-1.—(A) Structure of iconoscope; (B) simplified illustration of scanning.

be charged differently from its neighbor. These and other considerations permit a band pass of 4 mc. to give reasonably satisfactory results.

The whole problem of band pass may be approached from the point of view showing how much picture detail can be contained in a limited band of frequencies. Assume that a band pass of 4 mc. is all that is possible under the present standards. How much HORIZONTAL DETAIL (bits of picture detail on a horizontal line) is then possible? The period of a 4 mc.-signal is 0.25 μs, which is the time required by the electron beam to scan across two adjacent elements. Because 15,750 lines are scanned in one second, the period of one line is 63.5 μs. From this, the time used during the retrace (10.2 μs) must be subtracted to give the actual period of one line. The period of one line is then 53.3 μs, and the number of cycles per line is

$$\frac{53.3}{0.25} = 213 \text{ (approx.)}$$

The number of elements per line is therefore approximately 2x213=426 or less than half the 1,000 assumed previously for simplicity.

VERTICAL DETAIL depends on the number of horizontal lines scanned per picture frame. This may be illustrated by the use of figure 12-1. Assume that in line 3 each black dot (picture element) is divided into two dots and placed one above the other within the confines of line 3. When the beam scans the line, both dots will be covered simultaneously and only one signal will be available at the output. If the beam width is made smaller and twice as many lines are scanned, a signal will be produced from both black dots; that is, the vertical detail will be improved.

In the complete scan of one picture frame many lines are lost during flyback time. These lines are therefore not effective in producing vertical detail. It may be assumed that there are 380 horizontal lines that are effective in producing vertical detail. The number of picture elements per frame is

$$426 \times 380 = 161{,}880;$$

and at 30 frames per second, the total number of cycles produced is

$$161{,}880 \times 30 = 4{,}856{,}400.$$

As has been stated, a band pass of 4 mc. will give reasonably satisfactory results.

The Problem of Flicker

The eye retains an image for a fraction of a second (about 1/15 second) after the image is formed on the retina. This characteristic of the eye is utilized in moving pictures and television. Actually, it is because of this characteristic that it is possible to have moving pictures or television.

Moving-picture films are composed of a series of individual pictures (frames) that are shown on the screen in quick succession. The illusion of motion comes about because the figures may be displaced slightly in succeeding frames; and if enough frames are shown per second, the figures appear to move because of the rapid sequency of the frames and the persistence of vision. At approximately 15 frames per second the motion appears continuous, but there is a pronounced flicker. At 24 frames per second, some flicker is present; however, it is much less objectionable than at 15 frames per second. To reduce the flicker still further, a special shutter arrangement is used. The shutter cuts off the light from the screen while a new frame is moved into position. It also cuts off the light from the screen once more while the picture frame is stationary. Thus the shutter divides the presentation of every frame into two equal time intervals. This has essentially the same effect as increasing the frame frequency to 48 frames per second.

In television, somewhat the same problems of presentation are encountered. To keep the flicker from being objectionable, 30 complete frames per second are shown. Flicker is further reduced by the use of interlaced scanning, which has essentially the same effect as increasing the frame frequency to 60 frames per second without increasing the horizontal scanning speed, and without increasing the bandpass requirements of the composite TV signal.

Interlaced scanning is illustrated in figure 12-2. As has been mentioned before, band-pass considerations, the problems of synchronization, and the necessity for detail lead to the choice of 525 horizontal scanning lines per frame. To reduce flicker by means of interlaced scanning, the electron beam scans the odd-numbered lines first and then the even-numbered lines. Thus, two scans (FIELDS) are necessary to complete one FRAME. For example, as shown in figure 12-2, the sweep for the first field begins on the left side of line 1. The beam moves across the image plate at a slight downward angle (pulled

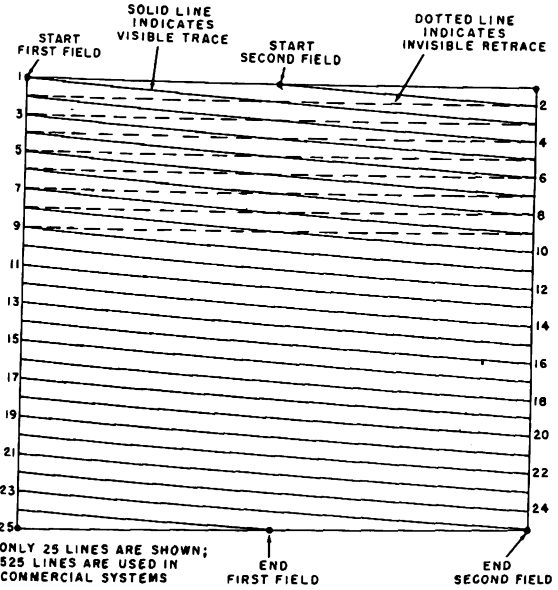

START FIRST FIELD
SOLID LINE INDICATES VISIBLE TRACE
START SECOND FIELD
DOTTED LINE INDICATES INVISIBLE RETRACE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
ONLY 25 LINES ARE SHOWN; 525 LINES ARE USED IN COMMERCIAL SYSTEMS
END FIRST FIELD
END SECOND FIELD

Figure 12-2.—Interlaced scanning.

vnward by the vertical deflection coils). At end of the line, the electron beam is blanked during the retrace to the left side of line 3. .s process is continued until the middle of e 525 is reached (only twenty-five lines are wn in the figure). Therefore, 262.5 lines are nned in the first field. When the beam reaches middle of the last line, it is blanked out and urned to the middle of line 2 where the trace the second field starts. The even-numbered s are scanned in sequence until the end of 524 is reached. At that instant the beam is nked out and returned to the beginning of line nd the whole process is repeated.

In order to keep the movement of the electron ms in both the camera and picture tubes in), and in order to blank out the signals from picture tube during the horizontal and verti- retrace periods, synchronizing (sync signals) blanking signals are sent out by the trans- er.

Synchronizing and Blanking Signals

3lanking signals (voltages) are used in both camera tube and the picture tube control uits to cut off the electron beam at the end horizontal scan line so that the return trace not be active in producing picture signals ne transmitter or picture elements at the iver. Blanking signals are also used to blank out the vertical return trace following the scan of each field.

Included with the blanking voltages (actually superimposed on them) are the synchronizing pulses that trigger the horizontal and vertical sweeps in the camera tube and the picture tube. One set of pulses, called the HORIZONTAL SYNC PULSES, synchronizes the horizontal sweep at the correct instant 15,750 times a second. Another set of pulses, called the VERTICAL SYNC PULSES synchronizes the vertical sweep at the correct instant 60 times a second.

For the horizontal scan, the sequence is as follows: (1) The signal is blanked out when the trace reaches the right-hand side of the screen, (2) an instant later the horizontal sync pulse arrives and the trace returns to the left-hand side of the screen, (3) the next horizontal trace begins, and (4) an instant later the blanking pulse is removed and the trace is visible until it reaches the right-hand side of the screen.

For the vertical scan, the sequence is as follows: (1) The signal is blanked out at the end of the first field (at end of line 262.5), (2) the vertical sync pulse arrives and the trace returns to the middle of line 2 at the top of the screen, (3) the next vertical sweep begins, and (4) the blanking signal is removed. During the second field, the lines missed on the first field are filled in.

In order to keep the horizontal sweep locked in step during the vertical retrace period and in order to produce interlaced scanning, the vertical sync pulses have a special serrated form and are preceded and followed by equalizing pulses. The composite video signal (the complete signal, including video and sync pulses), particularly the vertical and horizontal sync pulses, will have more meaning when the method of separating the pulses is described later in the chapter.

All television receivers must perform essentially the same functions. They must be able to select the desired carrier frequency, amplify the required band of frequencies, separate and demodulate the video and audio frequencies, separate and utilize the sync pulses, and finally reproduce the picture on the screen and the sound at the loudspeaker. How well each of these jobs is accomplished depends, in a large measure, on the design and the quality of the television receiver.

Beginning with the antenna, the remainder of this chapter explains, in general terms, the sequence of events that translates the television signal into sound and video information at the outputs of the receiver.

TELEVISION ANTENNAS AND TRANSMISSION LINES

At television frequencies, RF energy does not follow the curvature of the earth for great distances. The best reception generally, is experienced within a line-of-sight distance from the transmitter antenna. Circumstances may be such that good reception may extend beyond this distance, but the signal strength is rapidly attenuated with an increase in distance. In the "fringe area," beyond the area of good reception, the choice of a television antenna becomes increasingly important.

VHF Antennas

The dipole is effective in areas where the signal is strong and is received from only one direction. The dipole is resonant at only one frequency; however, it has a sufficiently broad response to receive the 6-mc. frequency span of a TV signal. (This includes the video and sound carriers and their sidebands.) As a matter of fact, a dipole cut to the proper length for channel 4 will serve fairly well for channels 2, 3, 4, 5, and 6, if the signal is sufficiently strong. A dipole cut to the proper length for channel 10 will also serve fairly well for channels 7, 8, 9, 10, 11, 12, and 13, if the signal is sufficiently strong.

A list of commercial television channels by frequencies is given in table 12-1.

Table 12-1.—Commercial television channels.

(Each channel has a width of 6 megacycles; sound carrier is 4.5 megacycles above picture carrier.)

Channel number	Picture-carrier frequency	Sound-carrier frequency	Channel number	Picture-carrier frequency	Sound-carrier frequency	Channel number	Picture-carrier frequency	Sound-carrier frequency
	mc.	mc.		mc.	mc.		mc.	mc.
2	55.25	59.75	29	561.25	565.75	56	723.25	727.75
3	61.25	65.75	30	567.25	571.75	57	729.25	733.75
4	67.25	71.75	31	573.25	577.75	58	735.25	739.75
5	77.25	81.75	32	579.25	583.75	59	741.25	745.75
6	83.25	87.75	33	585.25	589.75	60	747.25	751.75
7	175.25	179.75	34	591.25	595.75	61	753.25	757.75
8	181.25	185.75	35	597.25	601.75	62	759.25	763.75
9	187.25	191.75	36	603.25	607.75	63	765.25	769.75
10	193.25	197.75	37	609.25	613.75	64	771.25	775.75
11	199.25	203.75	38	615.25	619.75	65	777.25	781.75
12	205.25	209.75	39	621.25	625.75	66	783.25	787.75
13	211.25	215.75	40	627.25	631.75	67	789.25	793.75
14	471.25	475.75	41	633.25	637.75	68	795.25	799.75
15	477.25	481.75	42	639.25	643.75	69	801.25	805.75
16	483.25	487.75	43	645.25	649.75	70	807.25	811.75
17	489.25	493.75	44	651.25	655.75	71	813.25	817.75
18	495.25	499.75	45	657.25	661.75	72	819.25	823.75
19	501.25	505.75	46	663.25	667.75	73	825.25	829.75
20	507.25	511.75	47	669.25	673.75	74	831.25	835.75
21	513.25	517.75	48	675.25	679.75	75	837.25	841.75
22	519.25	523.75	49	681.25	685.75	76	843.25	847.75
23	525.25	529.75	50	687.25	691.75	77	849.25	853.75
24	531.25	535.75	51	693.25	697.75	78	855.25	859.75
25	537.25	541.75	52	699.25	703.75	79	861.25	865.75
26	543.25	547.75	53	705.25	709.75	80	867.25	871.75
27	549.25	553.75	54	711.25	715.75	81	873.25	877.75
28	555.25	559.75	55	717.25	721.75	82	879.25	883.75
						83	885.25	889.75

The length, L (in feet) of each of the two uarter-wave sections of the dipole cut for a articular frequency, f (in megacycles), is deermined by the following formula:

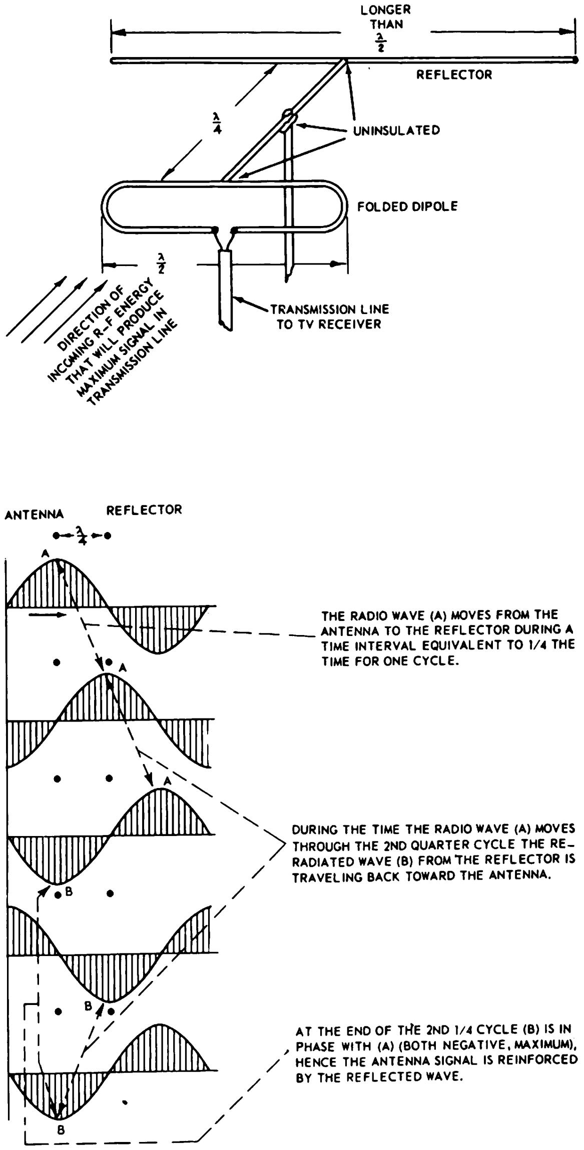
$$L = \frac{234}{f}.$$

The impedance of a simple dipole antenna is pproximately 73 ohms at its resonant frequency. 'he transmission line connecting the dipole to he receiver should also have a characteristic mpedance of 73 ohms, if no impedance matchng device is used. Likewise, the television reeiver input should have an impedance of 73-hms if no matching device other than the ransmission line is used.

Ghosts, essentially double images, will apear on the television screen if there is a time elay between the signals arriving at the reeiving antenna directly from the transmitter ntenna and those arriving after taking a longer oute. The signals taking the longer route may pproach the receiving antenna after being relected from a building or other object. Some of hese out-of-phase signals may return to the ntenna after being reflected more than once, nd thus they will produce more than one ghost ecause of the differences in time delay.

The folded dipole has the same directivity receives equally well from both sides) as the imple dipole. However, it has an impedance of 00 ohms and a higher gain. Most of the newer elevision receiving sets require 300-ohm lines, 'hich match 300-ohm folded-dipole antennas.

Some type of directional array is commonly sed with the folded dipole. A schematic diaram of a folded dipole and reflector is shown ı figure 12-3. The reflector is longer than the ipole and is placed a quarter-wave length bend it. Maximum signal voltage is developed / signals arriving from the direction of the lded dipole. Signals arriving from the direction the reflector are greatly attenuated.


LONGER THAN $\frac{\lambda}{2}$
REFLECTOR
$\frac{\lambda}{4}$
UNINSULATED
FOLDED DIPOLE
$\frac{\lambda}{2}$
TRANSMISSION LINE TO TV RECEIVER
DIRECTION OF INCOMING R-F ENERGY THAT WILL PRODUCE MAXIMUM SIGNAL IN TRANSMISSION LINE
ANTENNA
REFLECTOR
$\frac{\lambda}{4}$
A
A
A
B
B
B

THE RADIO WAVE (A) MOVES FROM THE ANTENNA TO THE REFLECTOR DURING A TIME INTERVAL EQUIVALENT TO 1/4 THE TIME FOR ONE CYCLE.

DURING THE TIME THE RADIO WAVE (A) MOVES THROUGH THE 2ND QUARTER CYCLE THE RERADIATED WAVE (B) FROM THE REFLECTOR IS TRAVELING BACK TOWARD THE ANTENNA.

AT THE END OF THE 2ND 1/4 CYCLE (B) IS IN PHASE WITH (A) (BOTH NEGATIVE, MAXIMUM), HENCE THE ANTENNA SIGNAL IS REINFORCED BY THE REFLECTED WAVE.

Figure 12-3.—Simple directional antenna array.

Maximum signal voltage is developed by diation arriving on the folded-dipole side beuse the signal voltages induced in the dipole e reinforced by signals reradiated from the flector. The reradiated signals have the proper ase to reinforce the signals originally induced the dipole, as illustrated. The energy abrbed in and reradiated from the reflector vels a half-wave length farther than the energy sorbed originally in the dipole. To this is ded the 180° phase reversal upon reflection. e total shift is therefore 360°, which causes the two energy components (the one originally absorbed in the folded dipole, and the one reradiated from the reflector) to combine in phase.

Energy arriving from the direction of the reflector will be attenuated because the energy absorbed from the direct wave at the dipole and the reradiated energy from the reflector are 180° out of phase.

The addition of the reflector therefore increases the gain of the antenna in one direction and reduces the gain in the opposite direction. The reduction in gain in the opposite direction is particularly important when it is desired to suppress ghosts caused by reflected energy arriving at the rear (side of the antenna opposite from the transmitter) of the antenna.

Simplified schematic diagrams of some popular types of television receiver antennas are shown in figure 12-4. The Yagi array provides high gain and high directivity at its resonant frequency. If it is desired to obtain maximum signal strength for one station, the Yagi array is a logical choice. Its band-width limitations preclude its use when more than one channel is to be received with maximum signal strength.

The conical antenna tunes broadly; that is, the impedance (300 ohms) remains essentially constant over a wide frequency range. The frequency range is broad enough to accommodate channels 2 through 13.

Combination high-band and low-band directional antennas are used extensively. The low band is usually tuned to channel 4 and the high band is tuned to channel 10. Thus, reasonably good coverage through the VHF band is obtained. Both dipoles are connected in parallel.

The antennas shown are some of the simpler types. There are many variations and special combinations, many of them having features not found in other antennas. The primary purpose of all TV antennas, however, remains the same: to intercept the maximum amount of desired signal energy and to make it available at the input of the transmission lines.

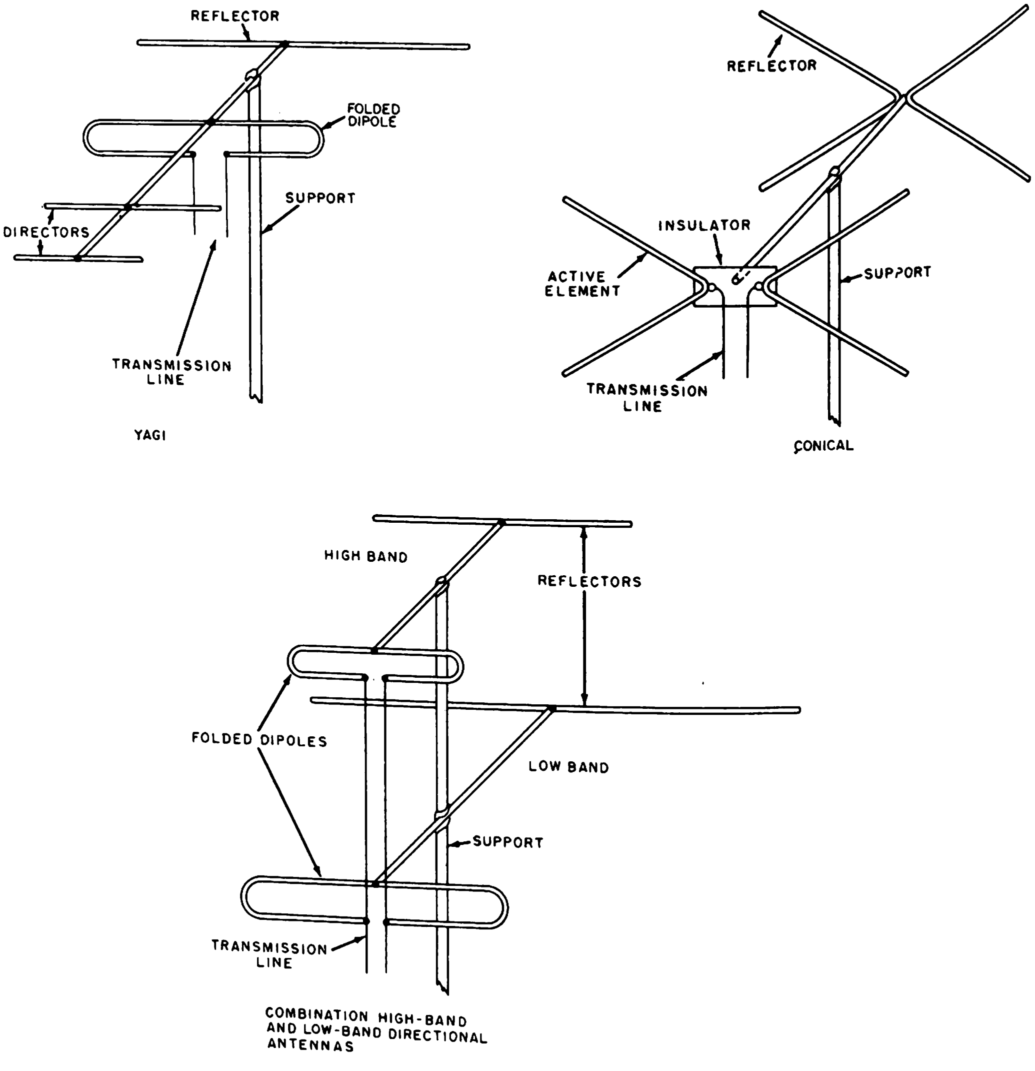
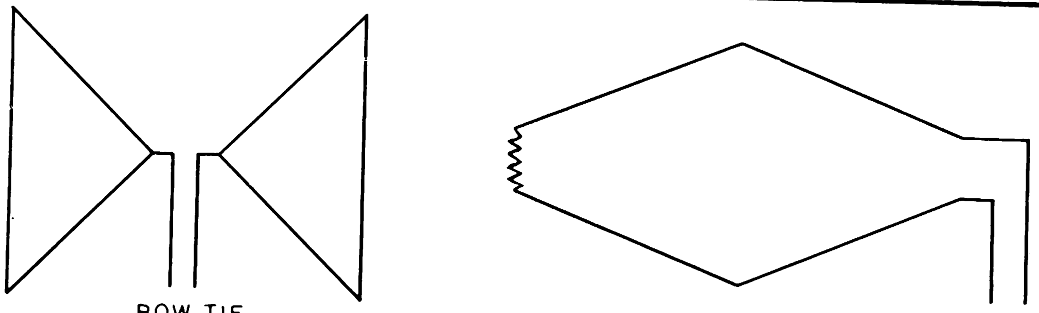
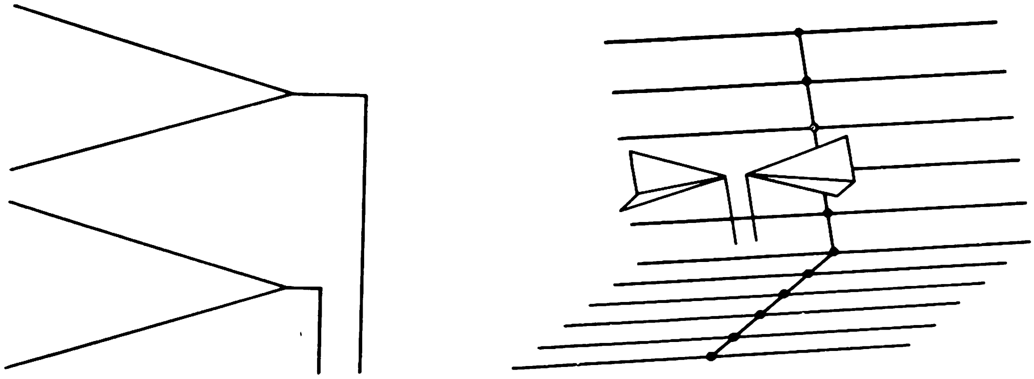


Figure 12-4. —Some common VHF television antennas.



BOW TIE

RHOMBIC



STACKED V

CORNER REFLECTOR

Figure 12-5.—Some common types of UHF antennas.

UHF Antennas

These antennas serve the same purpose as HF antennas. Because the frequency is higher, eir dimensions are smaller. Smaller dimen-ons mean that special configurations, not gen-rally employed at VHF, may be used. Of course, naller versions of the VHF antennas pre-ously mentioned may also be used.

The UHF band covers a wide range of fre-encies and therefore the BEST response is tained from an antenna designed to resonate at particular frequency; however, fairly good sponse may be obtained on adjacent channels. strong signal areas, antennas that are designed cover the whole UHF range may produce a tisfactory signal.

Schematic diagrams of some common types UHF antennas are shown in figure 12-5. The w-tie, or triangle dipole, antenna tunes broadly and has a bidirectional pattern. It is very effective in strong-signal areas where the bidirectional pattern is not objectionable; that is, where reflected out-of-phase signals (that could cause ghosts) do not arrive at the side of the antenna opposite from the transmitter.

The rhombic antenna is of practicable size at UHF frequencies. It is highly directional and has high gain. Therefore, it may be used in fringe areas.

The stacked-V antenna is simple to construct and has high gain. Its principal disadvantage is the existence of rather large side lobes. In areas where there are pronounced reflections, it may not be advantageous to use this type of antenna.

The corner reflector has high gain and a good response pattern. Its principal disadvantage is that it is somewhat elaborate and expensive, but no more expensive than some stacked arrays.

Transmission Lines

In common with other electronic receiving equipments, the TV transmission line functions to convey (with minimum distortion and minimum loss) the signal from the antenna to the receiver. To satisfy these requirements, the line should be balanced to ground (that is, each of the conductors should have the same capacitance with respect to ground); and the primary of the input circuit should be center-tapped. Undesired signals induced in the line are thus balanced out and do not affect the operation of the receiver. To reduce losses, the transmission line should have low effective resistance, and the characteristic impedance should be the required value to match the antenna and the receiver input for maximum power transfer.

A number of transmission lines may be used with television receivers. For example, the twisted pair, the shielded pair, the coaxial line, or the twin line could be used.

Several factors, such as economy, flexibility, low loss, and impedance match, have led to widespread use of the 300-ohm twin line. The conductors, spaced at a distance of about 3/8 in., are embedded in a plastic ribbon. Although this type of line has several good features, it should be pointed out that weathering will change its characteristic impedance; and, because of a lack of shielding, its use may not be advantageous in areas where there is a large amount of electrical disturbances. Most shipboard and aircraft installations will utilize shielded transmission line, as they have for other VHF and UHF installations, and for the same purposes.

TELEVISION RF AMPLIFIERS, OSCILLATORS, AND MIXERS

Television tuners, like those of communications receivers, consist essentially of three parts: the RF amplifier, the oscillator, and the mixer. The function of the front end (composed of the RF amplifier, the oscillator, and the mixer) is to amplify the relatively weak input signal of the desired frequency, to produce a locally generated RF signal of the correct frequency, and to mix these two frequencies in such a way as to produce the chosen audio and video intermediate frequencies. Because of the wide band of frequencies (approximately 6 mc.) that must be passed, overcoupling and loading are employed to increase the frequency response.

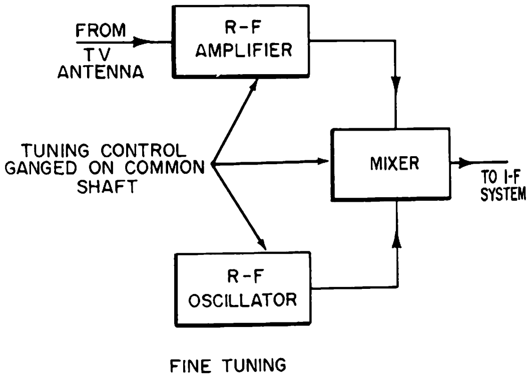


Figure 12-6.—Block diagram of a TV front end.

A block diagram of a typical front end is shown in figure 12-6. A number of different methods of tuning are employed by television receiver manufacturers. Rotary switches that connect the correct capacitors and inductors into the circuit are often employed. In some systems the "tuned line" is used, and in others separate components are connected for each channel. Turret tuners are also widely used. In this system of tuning, elements pretuned to the desired frequency may be plugged into a clip in the turret. For compactness and precision, printed circuits are sometimes employed.

Although certain problems are involved in continuous tuning, various forms of continuous tuners are used in a number of sets. The Inductuner, produced by the Mallory Company, is a popular tuner in which the inductance is varied over the tuning range while the capacitance remains constant.

RF Amplifiers

Because the television signal available at the input of the television receiver is weak, it is desirable to amplify the signal in a stage of RF amplification before it is applied to the mixer. Pentode tubes could be used to obtain high amplification, but the band of frequencies passed will be reduced unless the plate load resistor is reduced. If this is done, the gain is reduced and there is less advantage in using a pentode. Therefore, a triode having a high transconductance is commonly used. The triode is also inherently less noisy (because it has fewer grids) than the pentode, and this is a very great advantage when weak signals are being received. Obviously, if noise is amplified as much as the signal, "snow" other undesirable effects will appear on the een.

A popular RF amplifier, the CASCODE am- ier, combines the good features of both the ode and the pentode. A simplified circuit of type of cascode amplifier is shown in re 12-7.

Signals from the antenna are fed through ed circuit C1L1 to L2. The frequency re- nse is improved by effectively shunting L2 R1. Neutralization is not necessary for ration on the low band because of the com- t arrangement of the circuit and the tube con- tions. Likewise, neutralization is unneces- y for operation on the high band because L3 C2 (the distributed capacitance to ground) m a series resonant circuit (resonant at the ter of the high band) from the plate of V1 to und. The signal voltage across L3 varies the ential of the cathode of V2 with respect to und; and, because the grid is grounded, the al is applied effectively between the cathode the grid of V2. This arrangement, in effect, ifies the shunting distributed capacitance far as injecting undesired noise or degenera- into the grid circuit of V1 and V2 is con- ned.

Oscillators

Although many radio receivers employ a common tube for the oscillator and "mixer" it is usually more satisfactory, for frequencies used in commercial TV, to use a separate oscillator tube. Triodes are generally used in one of a number of possible circuit arrangements.

The ultraudion oscillator, similar in many respects to the Colpitts oscillator, is often employed. In other receivers, the Hartley circuit, the Colpitts circuit, or some form of push-pull arrangement is used. Oscillators are covered in *Basic Electronics*, NavPers 10087.

The fine tuning control is included in the oscillator circuit.

Mixers

The mixer tubes commonly used in TV receivers are triodes or pentodes. As in the case of RF amplifiers, triode mixers are less noisy than pentodes. However, they lack the gain of pentodes. Diodes introduce little or no noise, but they do not add gain. Energy is coupled from the oscillator into the mixer by capacitive or

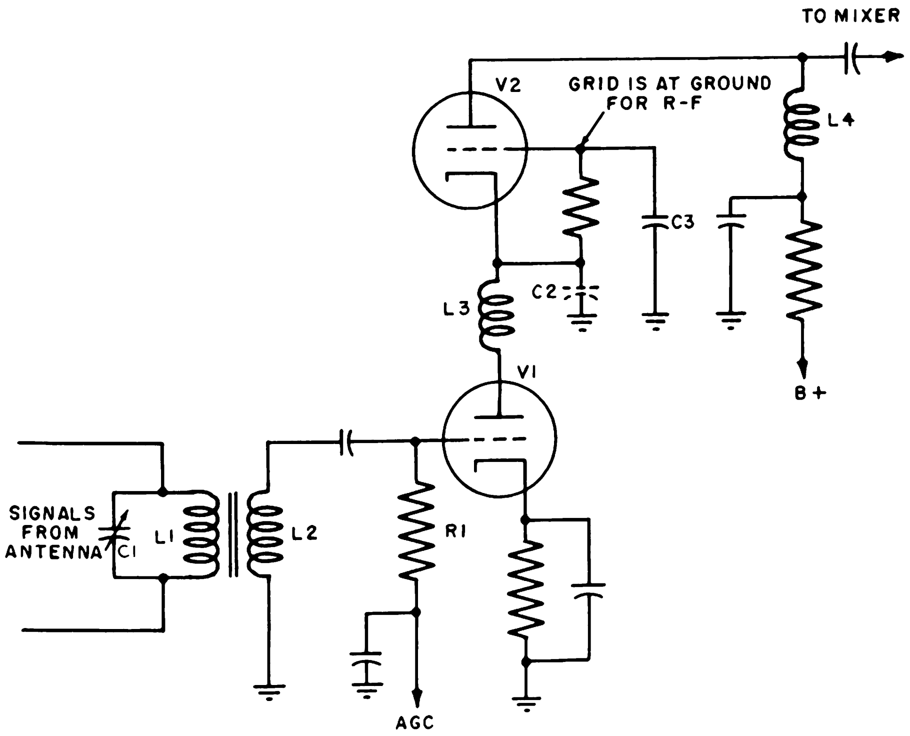


Figure 12-7.—Simplified circuit of a cascode amplifier.

inductive means. Mixers are also covered in *Basic Electronics*, NavPers 10087.

VIDEO IF AMPLIFIERS

Video IF amplifiers perform essentially the same functions that are performed by the IF amplifiers in superheterodyne radio receivers. However, band-pass considerations, vestigial sideband transmission, the necessity for trapping unwanted sound and video beat frequencies, and other factors make the design of video IF amplifiers somewhat difficult. A detailed discussion of the various types of video IF amplifiers is beyond the scope of this training course. However, the overall problems and some of the methods used to solve them are given.

Perhaps the best approach is to list the various problems inherent in the video IF section of a television receiver and to indicate one or more methods of solving each of the problems.

FIRST: For RF spectrum economy, the lower video sideband is greatly suppressed, and the video information is contained largely in the unsuppressed upper sideband. The remaining portion of the lower sideband is the VESTIGIAL SIDEBAND. The general form of the television RF spectrum is shown in figure 12-8.

Because it is impracticable to remove all of the lower sideband, the response curve of the video IF stage must have a special form. In general, the response curve is similar to that shown in figure 12-9. It may be seen that the video IF has a higher frequency than the sound IF. This results from the fact that the local oscillator operates at a higher frequency than that of the incoming signal.

That portion of the sidebands extending 1.25 mc. on both sides of the video carrier contains more energy than the sidebands beyond 1.25 mc. (fig. 12-8). This results from the fact that both upper and lower sidebands exist in the 1.25 mc. bandwidth in the immediate vicinity of the video carrier; whereas, beyond 1.25 mc., only the upper sideband is present. If the IF amplifiers were flat over the video band, the frequencies between 0 and 1.25 mc. on each side of the video carrier would be over emphasized at the second detector. In other words, the amplitude of these signal frequencies would be greater than that of the remaining frequencies in the upper sideband of the video signal because of the increased energy associated with the frequencies between 0 and 1.25 mc. on each side of the video carrier.

In order to achieve uniformity in the magnitude of the output video signal for all frequency components, the IF stages are adjusted so that the video IF carrier falls about half way down

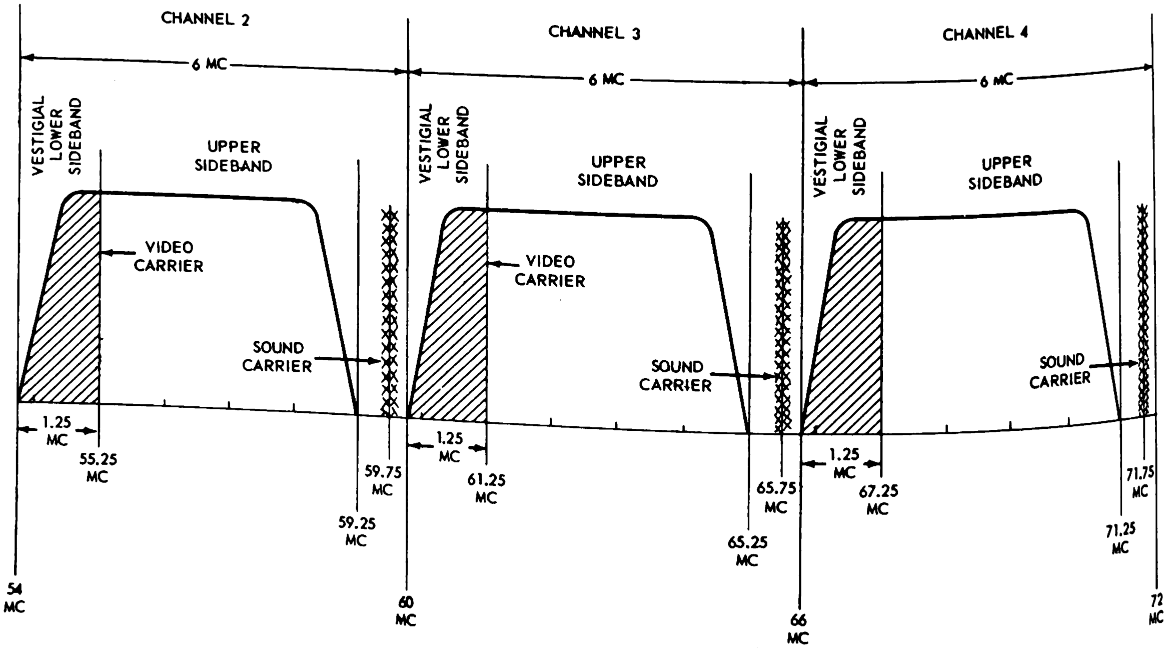
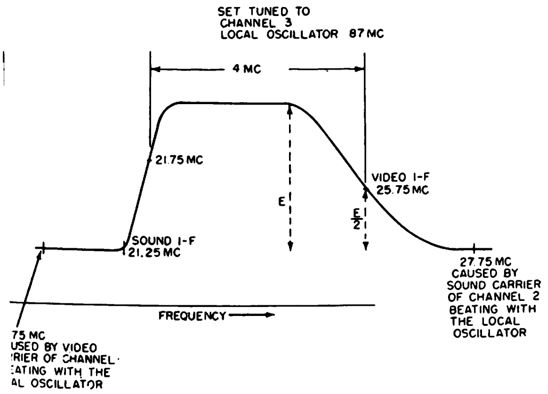


Figure 12-8.—RF spectrum for TV channels 2, 3, and 4.

he upper slope of the response curve. The are therefore amplified less than the highs, a more uniform response is achieved. For nple, a receiver tuned to channel 3 having a o carrier of 61.25 mc. may have a local llator frequency of 87 mc. The IF band- h will then extend from 87-61.25 = 25.75 to 5.25 = 21.75, or a total of 25.75-21.75 = 4 In the alignment of video IF stages this stment is very important.

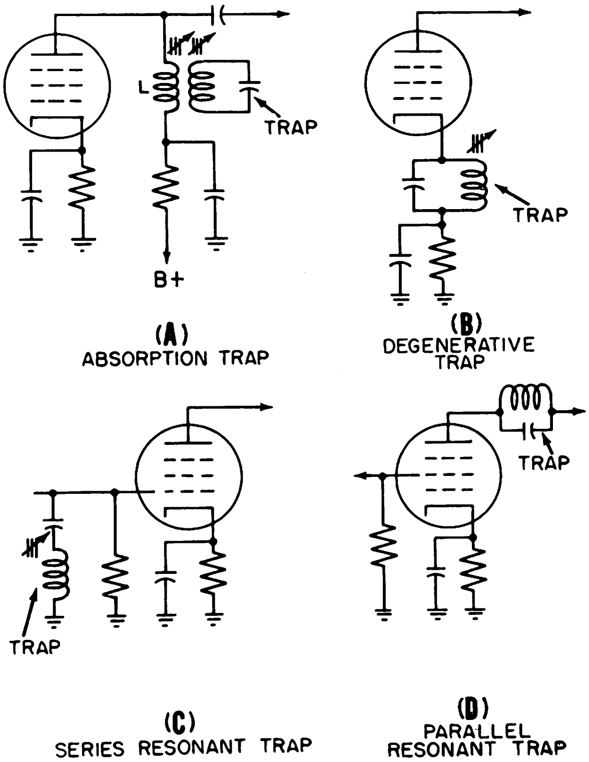
ECOND: Because the response character- of the RF and converter stages is intenally broadened to pass the desired range of uencies (6 mc.), the sides of the response e taper off gradually. This means that unrable frequencies may be passed through to video IF system, which may cause horizontal to appear on the picture. For example, it ssumed that a television receiver employing lit-sound system is tuned to channel 3. (In lit-sound system the audio is taken off ORE the detector stage; whereas, in rcarrier-sound systems the audio is taken FTER the detector stage.) The frequencies 75 mc., 21.25 mc., and 27.75 mc.) that may e trouble on the television screen are inted in figure 12-9. The 19.75-mc. beat , caused by the combining of the video car- (67.25 mc.) of channel 4 with the local llator frequency (87 mc.), is close enough desired frequencies to be passed through video IF system. Likewise, the 27.75-mc. note, caused by the combining of the sound r (59.75 mc.) of channel 2 with the local ator frequency (87 mc.), is close enough to ssed also. Of course, the sound IF (21.25 of channel 3 is the signal most likely to rough and must be trapped out at all costs.



igure 12-9.—Video IF response curve.

In INTERCARRIER systems this frequency, which beats with the video IF to produce the 4.5-mc. sound IF, must not be removed until after the sound IF (4.5 mc.) has been fed to the audio channels.

Some representative trap circuits are shown in figure 12-10. An absorption trap is shown in part A. The trap is tuned to the undesired frequency, and the output voltage (at the undesired frequency) developed across L is greatly reduced. It is therefore effectively removed from the input to the next stage.



(A)
ABSORPTION TRAP

(B)
DEGENERATIVE TRAP

(C)
SERIES RESONANT TRAP

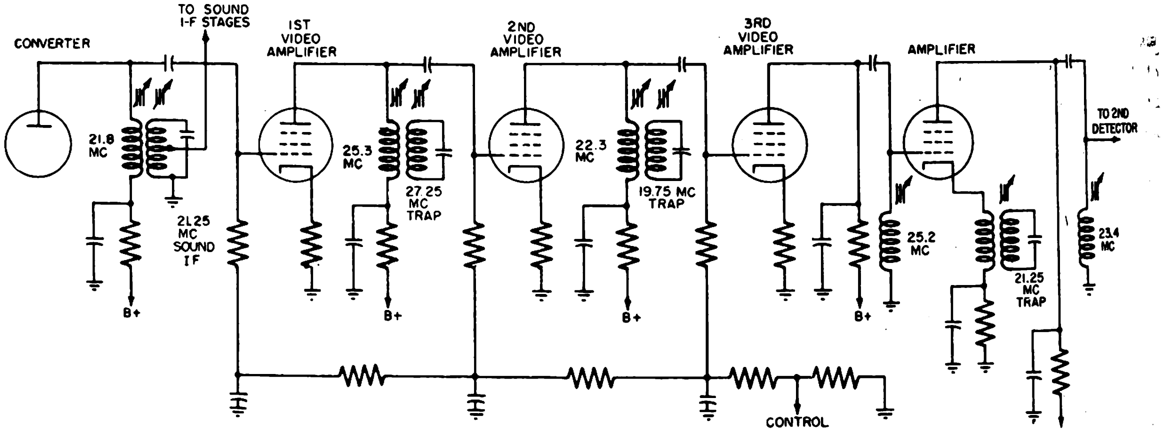
(D)
PARALLEL RESONANT TRAP

Figure 12-10.—Representative trap circuits.

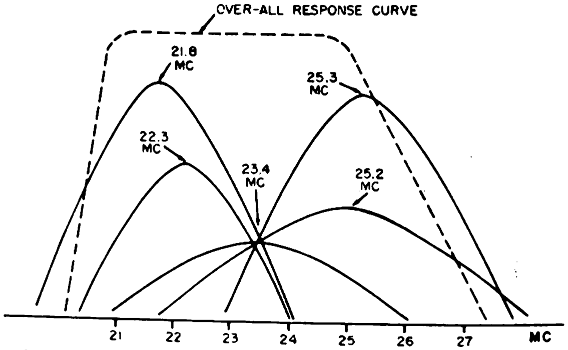
A degenerative trap is shown in figure 12-10 (B). At its resonant frequency (the undesired frequency) the trap offers a high impedance and this causes degeneration and reduced gain at that frequency.

A series resonant trap is shown in figure 12-10 (C). The trap is tuned to the undesired frequency and thus shunts these frequencies around the input of the stage.

The parallel resonant trap, shown in figure 12-10 (D), offers a high impedance to the undesired frequency. Thus, the offending voltage



(A) SIMPLIFIED I-F SECTION OF TV RECEIVER EMPLOYING SPLIT SOUND



(B) APPROXIMATE I-F RESPONSE CURVES

Figure 12-11.—IF section and response curves of a television receiver.

is dropped across the trap circuit and is not available at the input of the next stage.

Although trap circuits are commonly employed in the video IF stages, they are sometimes also included in the video amplifier of television receivers.

THIRD: In order to pass the necessary wide band of frequencies, most television receivers employ a stagger-tuned IF system. Each stage is tuned to a slightly different frequency to broaden the over-all response curve. As an example, it may be assumed that a quality television receiver, employing split sound and stagger tuning, is tuned to channel 3. It may be assumed also that the local oscillator operates at 87 mc.

The video IF is

87 mc.-61.25 mc. = 25.75 mc.

and the sound IF is

87 mc.-65.75 mc. = 21.25 mc.

The various tuned circuits in the IF section (together with the traps) are shown in figure 12-11 (A). The various frequencies in the vicinity of the video IF are so chosen that the overall response curve will be similar to that shown in (B).

VIDEO DETECTORS

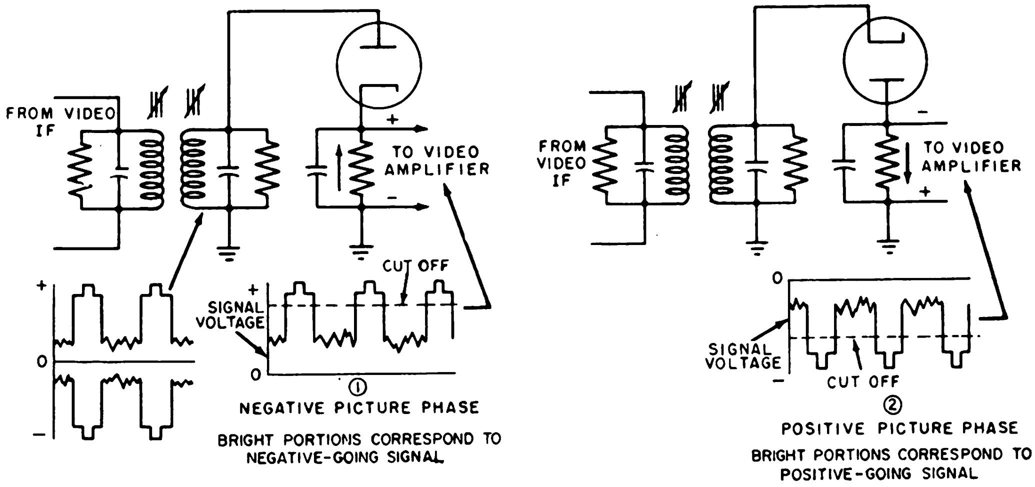
The video detector in a television receiver performs essentially the same function as the second detector in a superheterodyne amplitude-modulated radio receiver. It rectifies the signal (video and sync pulses) fed to it by the video IF tem, removes the IF components, and feeds remaining signal and sync information to the eo amplifier. Various circuit arrangements, ploying either diode electron tubes or crys-, are used by the manufacturers of television eivers.

One type of diode detector is shown in fig- 12-12 (A). Two methods of connecting the ector are shown. In part (1) the output has a ative picture phase, and in part (2) it has a itive picture phase.

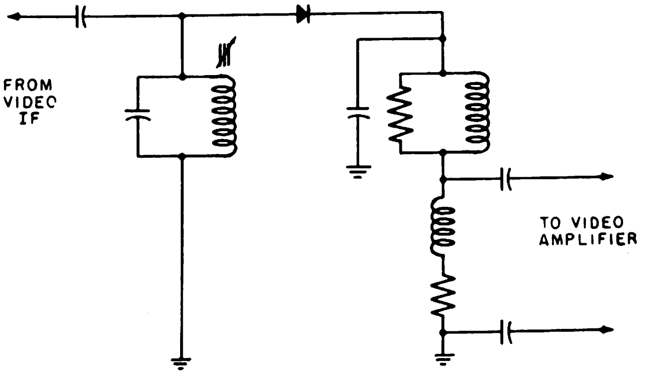
In figure 12-12 (A) (1), low amplitude itive-going picture signals correspond to brighter portions of the picture and higher plitudes correspond to progressively darker tions of the picture. This corresponds to the ative picture phase.

In figure 12-12 (A) (2), low amplitude negative-going picture signals correspond to the brighter portions of the picture and higher amplitudes correspond to progressively darker portions of the picture. This corresponds to the positive picture phase.

The concept of negative picture phase may be made clearer from the following considerations. A video signal having a negative picture phase will cause the cathode of the picture tube to be driven in a positive direction beyond cutoff during the blanking pulses. During the darker portions of the picture the cathode will be driven considerably in the positive direction, but not to cutoff. Consequently, a few electrons will reach the picture tube screen, and the screen will be relatively dark. During the brighter portions of



(A) VIDEO DIODE DETECTORS



(B) VIDEO CRYSTAL DETECTOR

Figure 12-12.—Video detectors.

the picture the cathode will be driven only slightly in the positive direction, and many electrons will reach the picture tube screen. The screen will therefore be relatively bright.

The concept of positive picture phase may be made clearer from the following considerations. A video signal having a positive picture phase will cause the grid of the picture tube to be driven negative below cutoff during the blanking pulses. During the darker portions of the picture the grid will be driven considerably negative, but not to cutoff. Consequently, fewer electrons will reach the picture tube screen, and the screen will be relatively dark. During the brighter portions of the picture the grid will be driven only slightly negative, and many electrons will reach the picture tube screen. The screen will therefore be relatively bright.

In the United States, negative transmission is used; that is, the television signal is transmitted with the negative picture phase. In certain other countries, positive picture transmission is used.

The output of the detector in the receiver may have a positive or a negative picture phase as indicated in figure 12-12 (A) (1) and (2), irrespective of the type of transmission used. In either case, the video amplifiers must supply a signal having a positive picture phase to the grid of the picture tube. If the signal is applied to the cathode of the picture tube, it must have a negative picture phase.

The strength of the signal at the output of the detector is not sufficient to drive the picture tube, and therefore one or more stages of video amplification are necessary.

The circuit arrangement of a video crystal detector is shown in figure 12-12 (B). The crystal performs essentially the same function as the diodes.

VIDEO AMPLIFIERS AND D-C RESTORERS

Video Amplifier Design Problems

After the video signal (containing the video information and the blanking and sync pulses) has been rectified in the second detector, it must be amplified in one or more video amplifiers before it is applied to the picture tube. Because a wide band of frequencies must be passed without discrimination by the video amplifiers, they must be carefully designed. Special high- and low-frequency compensating circuits must be used to extend the approximate range of frequencies passed from 30 cycles to 4 mc. In other words, FREQUENCY DISTORTION must be eliminated as much as possible.

The low-frequency video components include the low-frequency a-c variations (represented on the picture screen as portions of the image that do not contain fine detail), the blanking pulses, and the sync pulses (vertical and horizontal). The high-frequency video components are the high-frequency a-c variations that produce the fine detail on the picture screen. In addition to the low-frequency and the high-frequency components in the transmitted signal, there is a zero-frequency, or d-c, component present.

If all of the frequency components are not properly amplified in the video amplifier section, a distorted image will be produced. The distortion may appear as a lack of fine detail, a lack of image sharpness in the larger objects, or a lack of contrast.

In addition to frequency distortion, PHASE DISTORTION must also be eliminated as much as possible. In effect, phase distortion means that certain components (frequencies) that make up complex waveforms are not passed by the amplifier in the same length of time that other frequencies are passed. For example, in resistance-coupled amplifiers the coupling capacitor and the grid resistor, acting together, cause a phase shift that varies with the frequency.

Phase distortion may alter the background of the picture shown on the television screen; portions that should be white may be gray or even black. At the lower frequencies, excessive phase shift may cause larger objects to be blurred on the screen. At the higher frequencies, excessive phase shift causes the fine detail to be blurred.

Methods Of Eliminating Frequency And Phase Distortion

Video-frequency amplifiers are treated in *Basic Electronics*, NavPers 10087. It is pointed out that the average resistance-coupled amplifier has a flat response of only a few thousand cycles and is therefore not suitable for amplifying video frequencies.

In order to amplify the higher frequencies as much as the middle range of frequencies, it is necessary to use some form of HIGH-FREQUENCY COMPENSATION. This type of compensation commonly takes the form of SHUNT COMPENSATION or SERIES COMPENSATION or a combination of both.

In a resistance-coupled amplifier the output capacitance of the first amplifier stage, the distributed capacitance of the wiring, and the input capacitance of the second amplifier stage tend to shunt the high frequencies of the first stage to ground, thereby leaving less output voltage at these frequencies available to the second stage. The high frequencies are therefore not amplified as much as the middle range of frequencies.

This shunting effect may be compensated for (or the frequency range extended) by the use of a small inductor inserted in series with the plate load. The value of this inductor is so chosen that it will neutralize the distributed (output and input) capacitance of the circuit. That is, this inductor is so chosen that it, together with the distributed capacitance, will form a parallel resonant circuit that is resonant at a frequency where the response curve begins to fall appreciably. The frequency range is thereby extended. This type of compensation is called SHUNT COMPENSATION, and the coils are called PEAKING COILS.

SERIES COMPENSATION may also be used. In this case, a small inductor is added in series with the coupling capacitor and forms a series resonant circuit (resonant at a frequency where the response curve begins to droop) with the distributed capacitances. At resonance, increased current will flow through these capacitances, and larger voltages will be available at the input of the amplifier tube. To prevent a sharp peak in the response curve, a resistor is shunted across the series inductor.

In order to amplify the lower frequencies as much as the middle or high range of frequencies, it is necessary to use some form of LOW-FREQUENCY COMPENSATION. At low frequencies, the reactance of the coupling capacitor is large and much of the signal voltage is dropped there and is not available at the grid input. A large coupling capacitor could be used; but if this were done, the stray capacitance and leakage current would be increased. Of course, a coupling capacitor introduces some phase shift at low frequencies.

Both the loss in gain and the increase in phase shift at the lower frequencies may be compensated for in part by dividing the load resistor into two parts and bypassing one part with a capacitor. At the lower frequencies the plate load includes both resistors, and therefore the output voltage is higher. At the higher frequencies a portion of the load is effectively by-passed by the capacitor, and the output is proportionately lower.

D-c Restorers

The d-c restorer (or clamper) restores the d-c component of a pulse waveform after this component has been removed by the passage of the waveform through the coupling capacitor in the video amplifier stage. It is necessary to reinsert the correct d-c component at the input of the television picture tube if the correct level of background illumination is to be maintained. Also, if the correct d-c component is not reinserted, the blanking level will vary (instead of remaining constant, as it should), and retrace lines will appear on the screen during the time the blanking voltage is insufficient to cut off the picture tube during retrace.

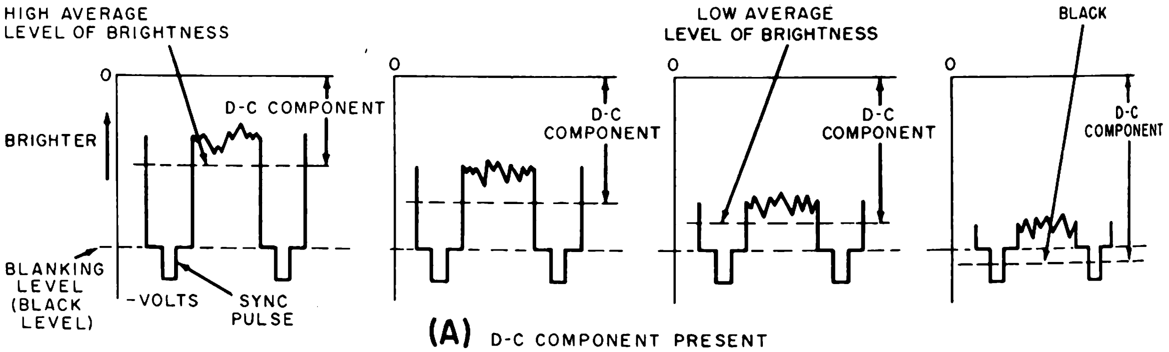
The average brightness of one scanned line may differ widely from the average brightness of another scanned line, as indicated in figure 12-13 (A).

The average d-c component depends on the average brightness of a line. A low d-c component in the negative direction means that there exists a high level of brightness during that line; a high d-c component in the negative direction means that there exists a low level of brightness during that line. The average d-c component therefore establishes the blanking level.

Figure 12-13 (B), illustrates what happens when the d-c component is removed by the passage of the video signal through a coupling capacitor. Although the picture tube may be biased so that it will not be driven in a positive direction beyond a certain value, nevertheless the blanking level will vary and the retrace will often be visible. The background brightness level will also differ from that at the transmitter.

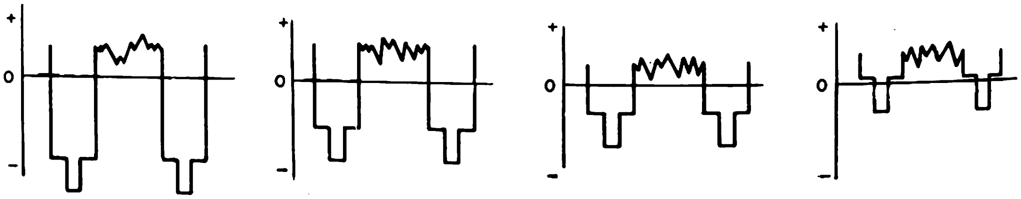
Simplified circuits of two types of d-c restorers are shown in figure 12-14. The function in each case is to restore the d-c component that was lost when the video signal passed through the coupling capacitor of the video amplifier. D-c restoration is accomplished by adding to the instantaneous a-c signal enough d-c voltage to bring the blanking voltage to the cutoff point.

Notice the similarity between the diode in figure 12-14, and the clamper in figure 4-20 of



(A) D-C COMPONENT PRESENT

WHEN THE VIDEO SIGNAL PASSES THROUGH A COUPLING CAPACITOR, THE D-C COMPONENT IS REMOVED, LEAVING AN A-C SIGNAL THAT VARIES ABOUT THE ZERO LINE



(B) D-C COMPONENT REMOVED

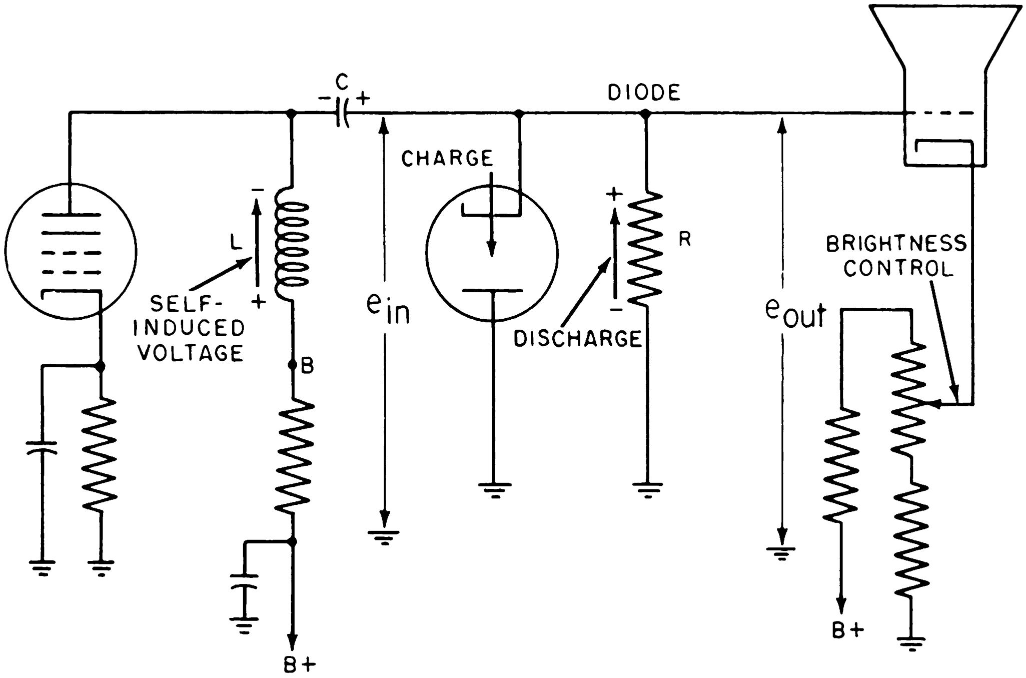
Figure 12-13.—Function of the d-c component in the video signal.

Chapter 4. The action of the diode restorer may be explained in the following manner. Without the diode the input signal voltage has the appearance of that shown in figure 12-13 (B). During the negative portion of the cycle (when the blanking and synchronizing pulses are active) the diode conducts because its cathode is negative and its plate is positive. This action occurs because the self-induced voltage across L opposes the B supply voltage and exceeds the value between point B and ground. Capacitor C charges rapidly through the diode and has the polarity indicated. The amount of the charge (voltage across C) depends on the strength of the input signal.

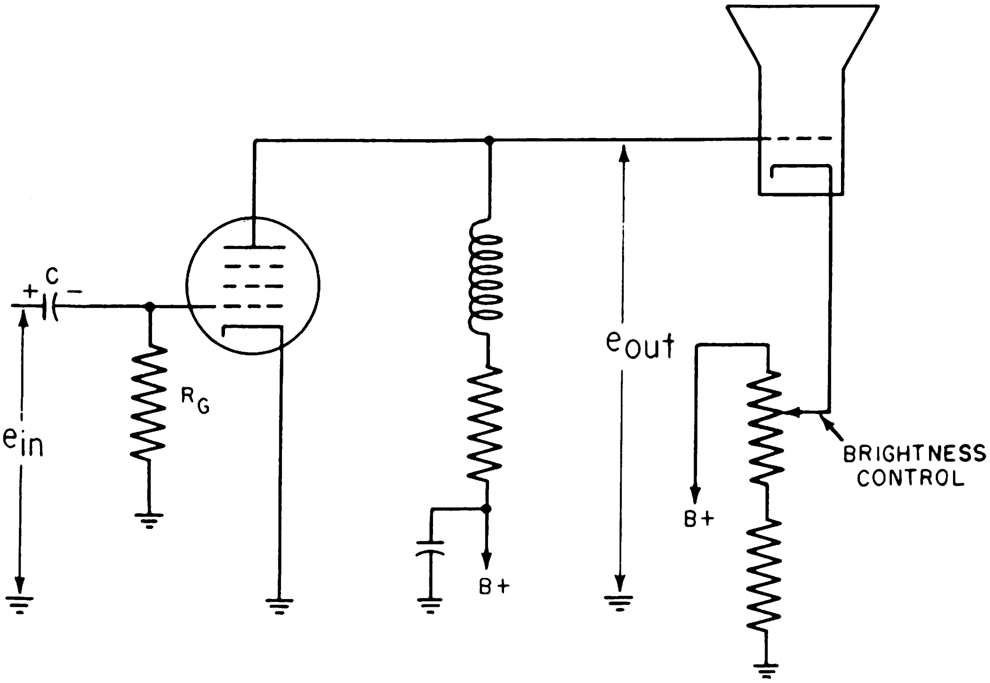
During the positive portion of the signal, shown above the O line in figure 12-13 (B), the diode cannot conduct, and C discharges relatively slowly through R. A positive potential, which reduces the bias on the picture tube, is thus applied between grid and cathode during the scan interval between the blanking pulses. During this interval the diode is effectively an open circuit, and the video signal appears across R in series with the d-c voltage supplied by C. The greater the input voltage, the less will be the net bias remaining on the grid of the picture tube, and the higher will be the average brightness. Thus the condition existing in figure 12-13 (A), is reestablished.

A grid-leak d-c restorer circuit is shown in figure 12-14 (B). The incoming video signal has a negative picture phase, and the d-c component is missing; the output video signal has a positive picture phase, and the d-c component is restored, or reinserted.

The action of the grid leak may be explained simply. There is no fixed bias on the tube, and the grid goes positive whenever a positive pulse is applied. Grid current flows, and C charges rapidly through the conducting grid circuit. If a large pulse is applied, a large amount of grid current flows and a large bias is developed. If a small pulse is applied, a small amount of grid current flows and a small bias is developed. These two actions tend to stabilize the plate current at the same level during the pulses of current. That is, the blanking pulses are lined



(A) DIODE D-C RESTORER



(B) GRID-LEAK D-C RESTORER

Figure 12-14.—Simplified circuits of d-c restorers.

up at the same level as they were before the d-c component was removed. During the interval between blanking pulses, C discharges slowly through R_g.

It should be emphasized that the bias remains essentially constant (because of the long time constant of C and R_g) during the interval between blanking pulses. If this were not true, the d-c component would be lost.

SYNCHRONIZING CIRCUITS

Up to this point interest has been focused primarily on delivering the video signal to the picture tube. Equally important, from the point of view of overall receiver operation, is the system by which the various circuits are synchronized with those at the transmitter and made to function together to produce the desired picture. As has been stated before, the blanking pulses and the horizontal and vertical synchronizing (sync) pulses are amplified in the various stages along with the video information. The video signals and the blanking pulses are applied either to the grid or to the cathode of the picture tube. However, the sync signals are removed from the composite video signal (generally in the last video stage) and applied to the horizontal and vertical sync circuits. In some instances the d-c restorer circuit is modified to serve also as a sync clipper.

After the vertical and horizontal sync signals have been removed (clipped) from the video signal, they must be amplified (if necessary) and separated from each other by means of filters. Following this, they are amplified and reshaped, according to the needs of the system, before they are applied to the oscillators. A block diagram of the synchronizing circuits is shown in figure 12-15.

The horizontal sync signal fires the horizontal oscillator at exactly the right instant to maintain the proper synchronization between the horizontal sweep in the receiver picture tube and the horizontal sweep in the transmitter camera tube. The output of the horizontal oscillator is formed into a sawtooth waveform; it is then amplified and applied to the horizontal deflection coils.

The vertical sync signal fires the vertical oscillator at the right instant to maintain the proper synchronization between the vertical sweep in the receiver picture tube and the vertical sweep in the transmitter camera tube. As in the case of the horizontal oscillator output, the vertical oscillator output is formed into a sawtooth wave (modified into a trapezoidal form); it is then amplified and applied to the vertical deflection coil.

Sync Separators

Sync separation, or sync clipping, may be accomplished by the use of circuits employing diodes, triodes, or pentodes. A simplified circuit of a diode sync separator is shown in figure 12-16. During the time the sync tip voltage is applied to the input the diode plate is positive with respect to the cathode, and capacitor C is charged through the low resistance of the conducting diode. Between pulses, capacitor C discharges through R and thus maintains a negative bias between plate and ground; and this cuts off all signals up to the blanking level. The bias is maintained at approximately the blanking level, and only the sync signal causes pulses of current

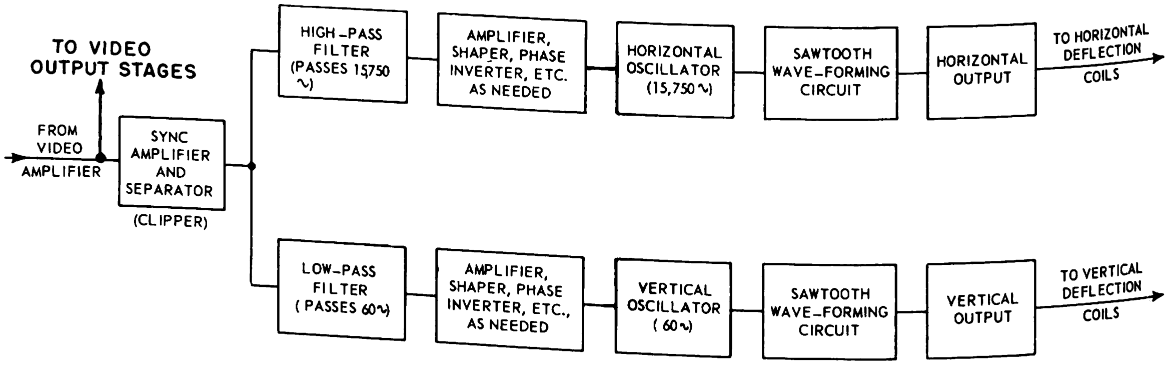

TO VIDEO OUTPUT STAGES
FROM VIDEO AMPLIFIER
SYNC AMPLIFIER AND SEPARATOR
(CLIPPER)
HIGH-PASS FILTER (PASSES 15,750 ∿)
AMPLIFIER, SHAPER, PHASE INVERTER, ETC. AS NEEDED
HORIZONTAL OSCILLATOR (15,750 ∿)
SAWTOOTH WAVE-FORMING CIRCUIT
HORIZONTAL OUTPUT
TO HORIZONTAL DEFLECTION COILS
LOW-PASS FILTER (PASSES 60∿)
AMPLIFIER, SHAPER, PHASE INVERTER, ETC., AS NEEDED
VERTICAL OSCILLATOR (60∿)
SAWTOOTH WAVE-FORMING CIRCUIT
VERTICAL OUTPUT
TO VERTICAL DEFLECTION COILS

Figure 12-15.—Block diagram of synchronizing circuits.

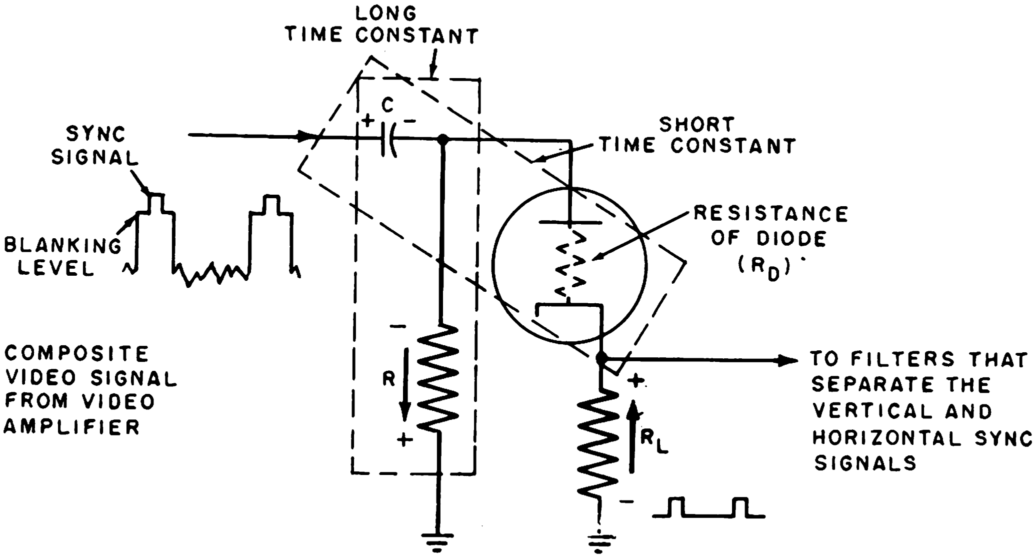

LONG TIME CONSTANT
C
SYNC SIGNAL
BLANKING LEVEL
SHORT TIME CONSTANT
RESISTANCE OF DIODE (R_D)
COMPOSITE VIDEO SIGNAL FROM VIDEO AMPLIFIER
R
R_L
TO FILTERS THAT SEPARATE THE VERTICAL AND HORIZONTAL SYNC SIGNALS

Figure 12-16.—Diode sync separator (sync clipper).

to flow through R_L, across which the output is taken. Thus, the sync signals have been clipped from the composite signal.

The output pulses consist of the horizontal sync pulses, the equalizing pulses, and the serrated vertical sync pulses. These pulses are fed to filter circuits that separate the vertical sync pulses from the horizontal sync pulses. These various pulses will be discussed presently.

The problems involved in removing the sync signals from the composite signal (sync clipping), and in amplifying, separating, and utilizing those signals to control the horizontal and vertical oscillators are treated only in a general way in this section. There are many methods of solving these problems and therefore a detailed treatment of each method is not possible in this training course.

SEPARATION OF VERTICAL AND HORIZONTAL SYNC PULSES

Because the repetition rate of the vertical sync pulses is 60 pulses per second and that of the horizontal sync pulses is 15,750 pulses per second, they may be separated by filters.

The high-pass filter used to pass and to shape the trigger voltages for the horizontal oscillator (a multivibrator or blocking oscillator) is shown in figure 12-17. The circuit in this figure has a short time constant with respect to the width of the horizontal pulse. The output signal is developed across R.

The leading edge of the square-wave input pulses causes a rapid charge of C through R. The trailing edge causes an equally rapid discharge of C through R. The flow of charge and discharge current through R causes the sharp spikes of output voltage, as shown in the figure. Only one spike in each pair (for example, the positive spike) is needed to trigger the horizontal oscillator. The other spike of the pair occurs at a time when the oscillator is insensitive to triggering pulses.

The low-pass filter used to pass and shape the trigger voltages for the vertical oscillator (a multivibrator or blocking oscillator) is shown in figure 12-18. The RC time constant is long with respect to the width of each serration in the vertical pulse. Because of the long time constant of the integrator circuit, C does not have time to discharge during the interval between serrations. However, because the RC time constant is short compared to the combined widths of the vertical pulse serrations, C charges up to the peak value during the time that the vertical pulse is applied (190.44 μs in the figure) and discharges to zero before the next horizontal pulse arrives.

The short time constant (with respect to the width of each horizontal pulse) of the differentiator circuit shown in figure 12-17, plus the fact

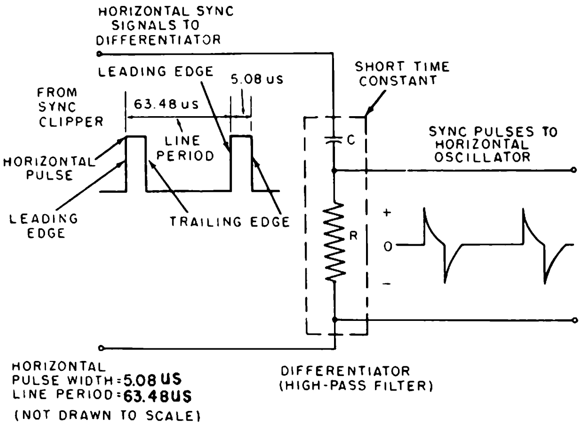


Figure 12-17.—High-pass filter for horizontal sync pulses.

that the output is taken across the resistor, (which retains no voltage charge), renders this circuit relatively insensitive to the longer, lower-repetition-rate pulses that control the vertical oscillator.

Because of the long time constant (with respect to the width of each horizontal pulse) of the integrator circuit shown in figure 12-18, the horizontal pulses have very little effect, and the equalizing pulses have even less effect. The only pulse that produces a useful output is the serrated vertical pulse. Sixty of these pulses occur each second, 30 for each of the two fields. The vertical pulses are serrated to provide the triggering action for the horizontal oscillator during the vertical retrace period.

THE FORM OF THE SYNCHRONIZING PULSES

Up to this point little has been said about the special form of the synchronizing pulses. The form and the timing of the synchronizing pulses are such that the horizontal and the vertical oscillators are triggered at exactly the right instant to keep the sweep in the camera tube and the sweep in the picture tube locked in step. Because the horizontal oscillator must be triggered even during the vertical retrace time (to prevent the horizontal oscillator from drifting out of control), the vertical pulse is serrated, as shown in figure 12-19. That is, the vertical pulse is chopped into six pieces. The fluctuations resulting from the serrations do not affect the operation of the vertical oscillator, but serve only to keep the horizontal oscillator properly triggered. The serrations are spaced so that they occur when the horizontal oscillator requires a trigger to keep it synchronized. Thus, the horizontal oscillator is working even while the electron beam is blanked out and being swept from the bottom of a frame to the top. About 20 lines per frame are lost during vertical retrace time. Some of these lines can be seen when the brilliance control is turned all the way up.

In addition to the serrations in the vertical pulse, equalizing pulses are necessary before and after each vertical pulse. The necessity for the equalizing pulses, labeled E in figure 12-19 (B), may be explained as follows: First, it is assumed that no equalizing pulses are used, as

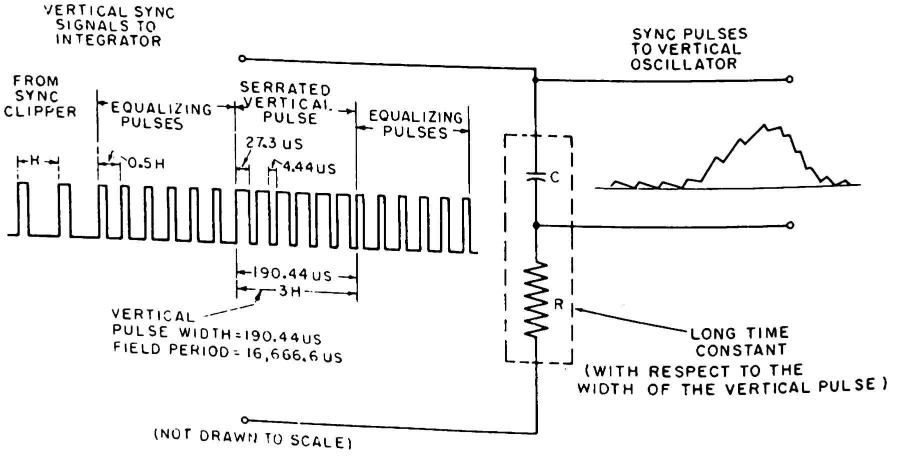

VERTICAL SYNC SIGNALS TO INTEGRATOR
FROM SYNC CLIPPER
H
EQUALIZING PULSES
0.5H
SERRATED VERTICAL PULSE
27.3 US
4.44US
EQUALIZING PULSES
190.44 US
3H
VERTICAL PULSE WIDTH=190.44US
FIELD PERIOD=16,666.6 US
(NOT DRAWN TO SCALE)
SYNC PULSES TO VERTICAL OSCILLATOR
C
R
LONG TIME CONSTANT (WITH RESPECT TO THE WIDTH OF THE VERTICAL PULSE)
INTEGRATOR (LOW-PASS FILTER)

Figure 12-18.—Low-pass filter for vertical sync pulses.

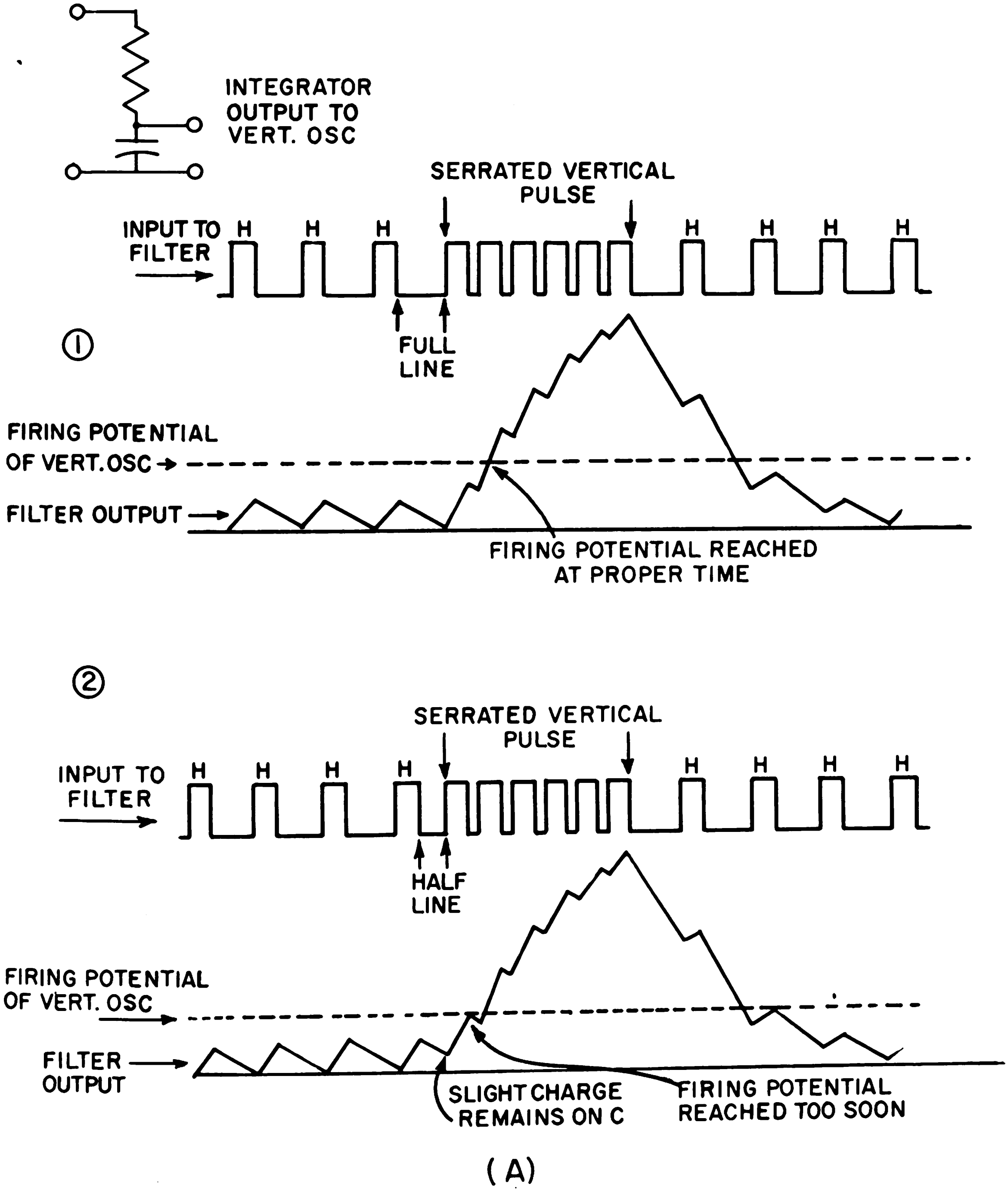
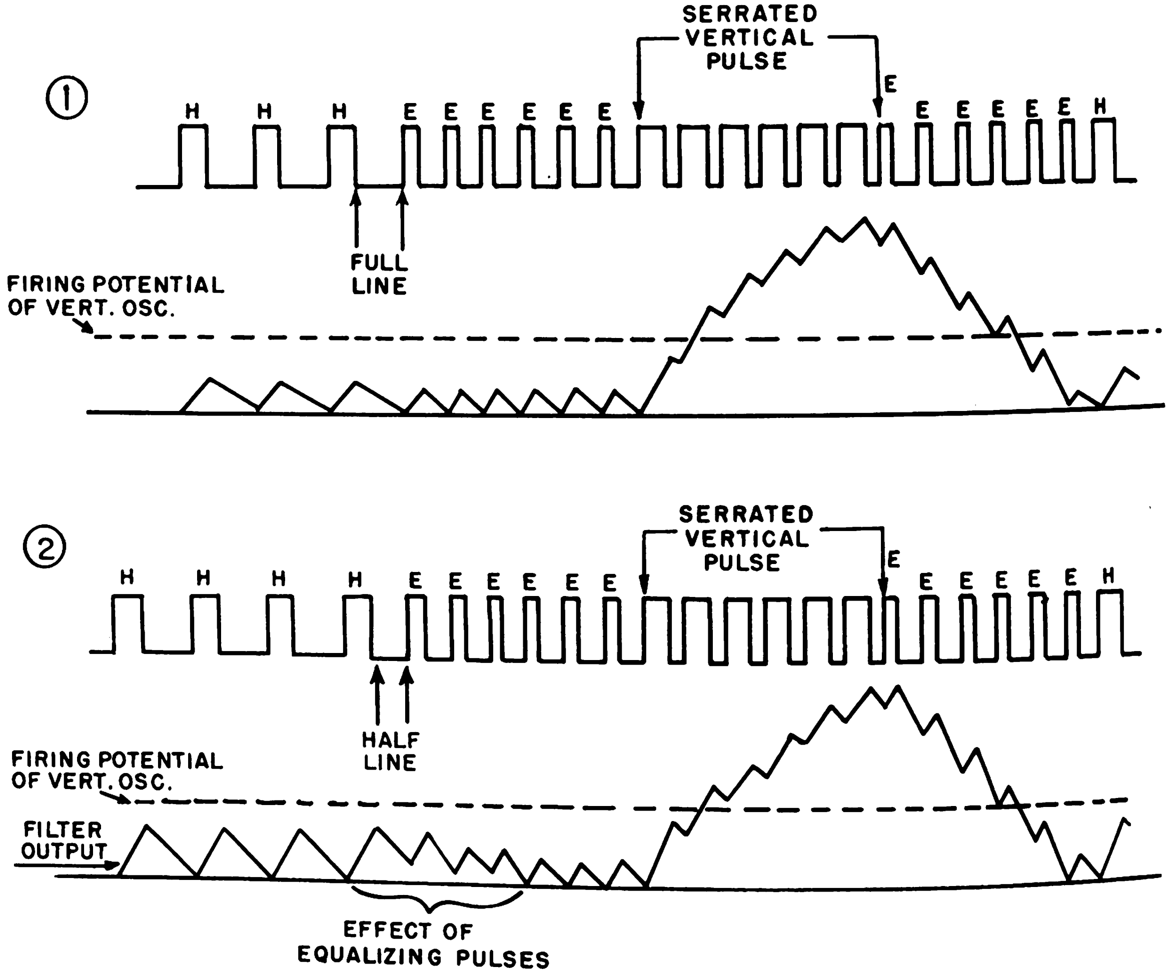


Figure 12-19.—(A) Effect without equalizing pulses.



(B)

Figure 12-19.—(B) Effect with equalizing pulses.

in figure 12-19 (A). If the vertical pulse is inserted at the end of the field which occurs simultaneously with the end of a full horizontal line (part ①), the firing potential of the vertical oscillator is reached at the correct time to produce the desired interlaced scan.

If the vertical pulse is inserted at the end of a field which occurs simultaneously with the end of a half horizontal line (part ②), the firing potential of the vertical oscillator is reached too early. This results from the fact that the slight charge in C, due to each horizontal pulse, does not have time to leak off before the vertical pulse arrives. The residual voltage across C, plus the voltage due to the vertical pulse, causes the vertical oscillator to fire a small fraction of a second too soon.

This situation is corrected, as shown in (B), by the use of equalizing pulses. The buildup of the vertical pulse across C now begins at the same point regardless of whether the vertical pulse arrives at the end of a full line or at the end of a half line. In other words, the equalizing pulses cause the potential on C to be at the same level (at the same time the vertical pulse arrives) regardless of whether the vertical pulse occurs at the end of a half line or at the end of a full line.

Figure 12-20 shows the overall picture of the sync pulses, both full lines and half lines. The pulses labeled A are the ones that fire the horizontal oscillator.

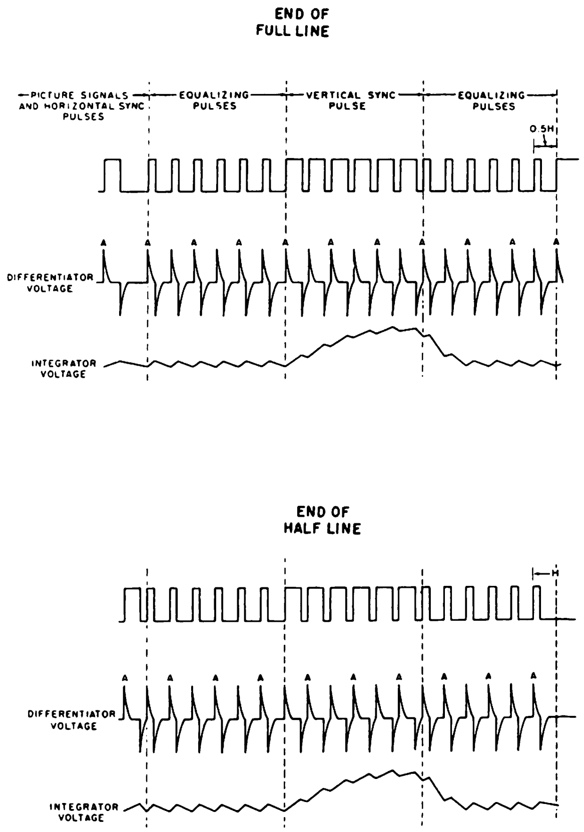


Figure 12-20.—Form of sync pulses showing the integrator and differentiator output voltages.

Sweep Circuits

The block diagram of figure 12-15 shows that after being separated and shaped, the horizontal and vertical sync pulses are applied to the horizontal and vertical sweep oscillators, respectively, so that they may be triggered at the correct instant to synchronize the receiver with the transmitter. Both the vertical and horizontal sweep oscillators, when fed into the correct circuits, produce sawtooth waveforms.

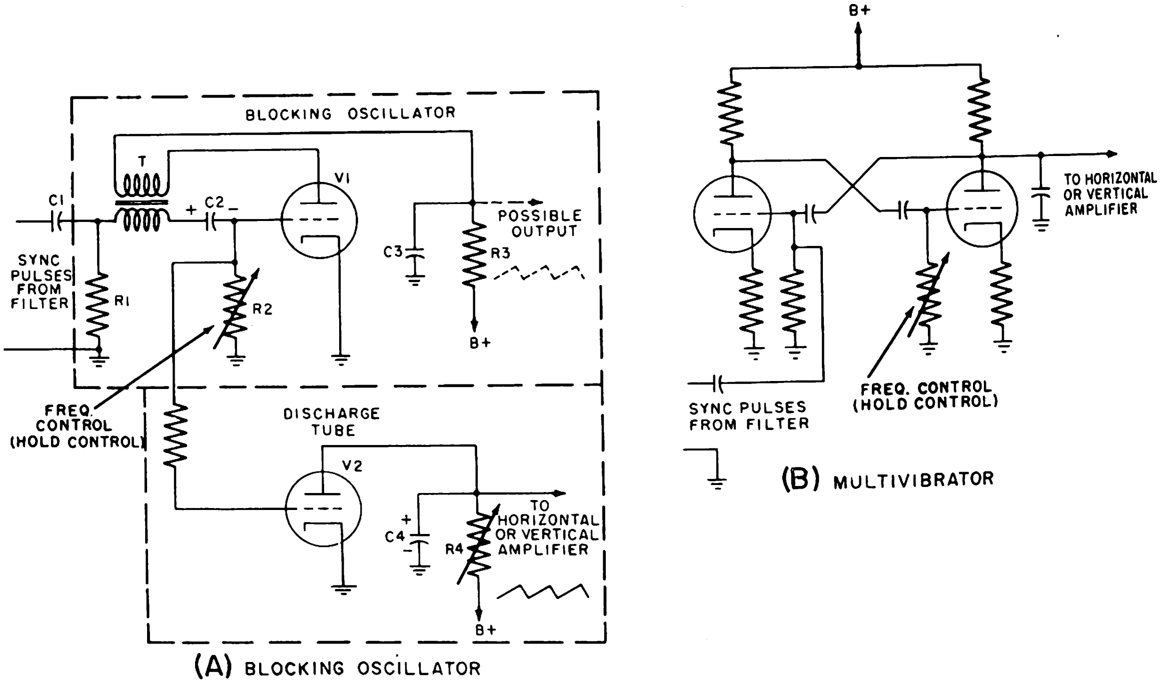
The sawtooth waveforms produced by the horizontal sweep oscillator are amplified and applied to the picture tube in a manner that will cause the electron beam to be deflected (swept) horizontally across the face of the tube. Likewise, the waveforms produced by the vertical sweep oscillator cause the electron beam to be deflected (relatively slowly) from top to bottom of the picture tube.

Multivibrators and blocking oscillators are two types of resistance-capacitance oscillators that are commonly used in the sweep circuits (vertical and horizontal) of television receivers. Chapter 5 of this training course covers multivibrators and blocking oscillators. Additional information on these subjects appears in *Basic Electronics*, NavPers 10087. A review of these sources will be time well spent.

BLOCKING OSCILLATOR

A simplified version of a blocking oscillator is shown in figure 12-21 (A). When plate and filament voltages are applied to the tube, plate current begins to flow. A voltage is induced in the grid circuit (via transformer T) that makes the grid positive with respect to ground, and plate current is thereby increased rapidly to saturation. Capacitor C2 charges rapidly during the time that grid current flows. At saturation the plate current and field about T stop increasing. The voltage induced in the secondary of T drops to zero, and therefore the induced positive grid voltage drops to zero. Capacitor C2 begins to discharge through R2 and the plate current falls; the field of T collapses. The voltage induced in the secondary of T is now a polarity that aids the discharge of C2. The grid therefore becomes more negative with respect to ground, and plate current falls rapidly to zero. When the plate current is zero, the voltage induced in T is zero. Capacitor C2 continues to discharge relatively slowly through R2. This action maintains a negative charge on the grid for an appreciable length of time. The time (equal to the period between the pulses produced by the oscillator) necessary for the negative charge to be reduced sufficiently to cause the tube to conduct again depends on the value of adjustable resistor R2. When the tube begins to conduct again, the cycle is repeated.

A sawtooth output could be tapped off across R3, but the waveform would be lacking in linearity and stability because of the loading effect on the oscillator. The sawtooth wave is developed because C3 charges relatively slowly through R3 during the relatively long time that V1 is cut off and discharges quickly through the tube during the relatively short time that the tube is conducting.


BLOCKING OSCILLATOR
T
C1
C2
V1
SYNC PULSES FROM FILTER
R1
R2
C3
R3
POSSIBLE OUTPUT
B+
FREQ. CONTROL (HOLD CONTROL)
DISCHARGE TUBE
V2
C4
R4
TO HORIZONTAL OR VERTICAL AMPLIFIER
B+
B+
TO HORIZONTAL OR VERTICAL AMPLIFIER
SYNC PULSES FROM FILTER
FREQ. CONTROL (HOLD CONTROL)

(A) BLOCKING OSCILLATOR

(B) MULTIVIBRATOR

Figure 12-21.—Television sweep oscillators.

The sawtooth output is more commonly obtained across the load resistor of a discharge tube. This arrangement is shown in figure 12-21 (A). The sharp positive pulse developed across R2 is coupled to the grid of V2. During the period when the positive pulse is not applied to the grid of V2, C4 charges relatively slowly at a uniform rate through R4; when the positive pulse is applied, C4 discharges rapidly through V2. The sawtooth voltage is therefore developed across R4.

MULTIVIBRATOR

One type of circuit, showing the sync input and sawtooth output, is shown in figure 12-21 (B). The sync pulses can control the firing of the multivibrator if the frequency of the multivibrator is close to the repetition rate of the sync pulses.

Automatic Frequency Control of the Horizontal Oscillator

In the sweep circuits discussed thus far, the horizontal and vertical sync pulses are fed from the filter directly to the horizontal and vertical sweep oscillators. This simple, direct system would be satisfactory if it were not for the presence of noise pulses that may cause the oscillators to fire at the wrong time. When the vertical oscillator fires at the wrong time, the picture is not properly synchronized vertically. That is, the picture bounces, or moves in jumps upward or downward across the screen. When the horizontal oscillator fires at the wrong time, the picture is not properly synchronized horizontally. That is, the picture tears or becomes streaked, giving the appearence that the picture is jumbled.

Although noise pulses may affect the operation of both the vertical and the horizontal oscillator, by far the worse effect is felt by the horizontal oscillator. The long time constant of the vertical filter makes it insensitive to the short bursts of noise energy, and the effect on the vertical oscillator is not generally objectionable.

The short time constant of the filter that feeds the sync pulses to the horizontal oscillator will permit the passage of short bursts of noise energy. Consequently, it is necessary to employ a control circuit that will effectively isolate the horizontal oscillator from the effects of noise pulses, and at the same time will permit the sync pulses to assume control.

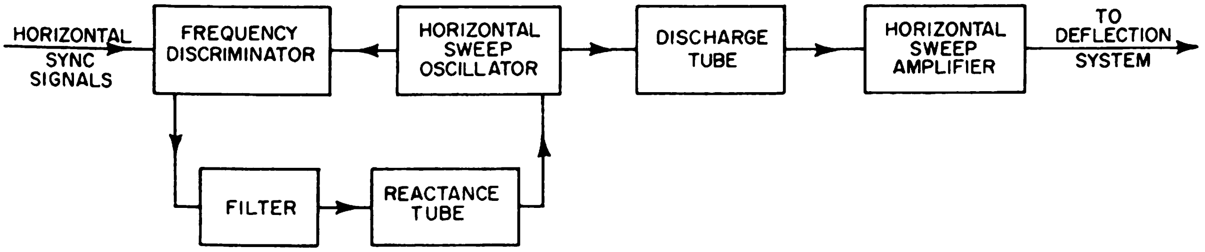
Two systems that will isolate the horizontal sweep oscillator from the effects of noise bursts are shown in figure 12-22. In the system shown in part A, two signals are applied to the frequency discriminator. They are horizontal sync signals and horizontal sweep oscillator signals. The frequency discriminator compares the frequency (or phase) of these signals and produces an output d-c voltage that depends on the differences between frequency (or phase) of the two signals. The output voltage, normally varying at a relatively slow rate, is fed via a low-pass filter to the grid of the reactance tube. This tube functions in such a manner that its output will change the frequency of the horizontal sweep oscillator to maintain its frequency exactly the same as that of the incoming horizontal sync pulses. Reactance tubes and frequency discriminators are treated in *Basic Electronics*, NavPers 10087, and chapter 5 of this course.

A second method of isolating the horizontal sweep oscillator from noise bursts is shown in figure 12-22 (B). As in the previous system, a frequency (or phase) discriminator is used. It compares the sync-signal input from the filter or sync amplifier with the input feedback from the horizontal sweep amplifier and produces a d-c output that is proportional to that difference. This d-c output is amplified and used in such a way as to cause the frequency of the horizontal sweep oscillator to lock in step with the incoming sync signals.

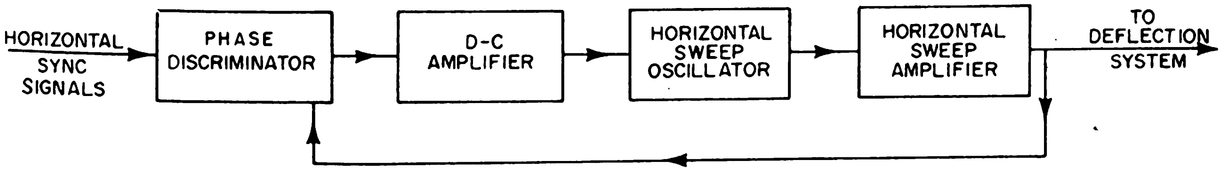
ELECTROMAGNETIC DEFLECTION SYSTEM

Electromagnetic rather than electrostatic deflection is commonly employed in television receivers. Whereas sawtooth VOLTAGE waves are used in electrostatic deflection, sawtooth CURRENT waves are used in electromagnetic deflection. It should be emphasized that more power is needed in the horizontal deflection system than in the vertical deflection system of a television receiver because of the greater number of deflections per unit time that must be accomplished by the horizontal deflection circuit. Because of the higher frequency involved, there are additional transformer and circuit losses. The horizontal deflection circuits must therefore be designed to handle much more power than the vertical deflection circuits.

If the deflection coils of a television receiver possessed inductance only, a properly applied sawtooth wave of voltage would cause a sawtooth



(A) SYNC SYSTEM EMPLOYING A DISCRIMINATOR & REACTANCE TUBE



(B) SYNC SYSTEM EMPLOYING A PHASE DETECTOR

Figure 12-22.—Systems of horizontal sync control.

current wave to flow through the coils. However, the deflection coils have the property of resistance as well as inductance, and therefore a modified sawtooth voltage wave must be applied to the coils. The desired modified voltage wave has a trapezoidal form, as shown in figure 12-23. In this instance, the desired voltage waveform is developed across the output plate-to-ground circuit of the discharge tube—that is, across C and R3. Resistor R3 has a low value, and has negligible effect during charge time.

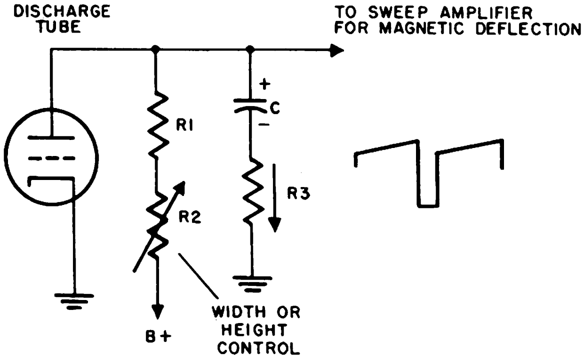


Figure 12-23.—Method of generating trapezoidal voltage waves.

The sweep amplifier for magnetic deflection is similar to the output stage of a radio receiver, except for the nature of the load. The simplified circuit of a vertical amplifier (the output stage) is shown in figure 12-24.

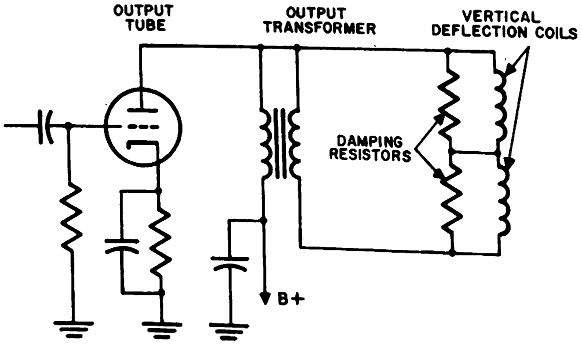


Figure 12-24.—Vertical amplifier.

There is a tendency for the inductance of the vertical coils, acting with the distributed capacitance, to set up spurious oscillations. These spurious oscillations may be damped out, in the case of the vertical deflection system, by resistors connected across the vertical deflection coils as indicated in the figure. A more complex system of damping is generally employed with horizontal deflection systems.

HIGH-VOLTAGE SUPPLY

A simplified circuit of a flyback (or kickback) high-voltage power supply commonly used in television receivers is shown in figure 12-25. In this high-voltage system the horizontal output transformer serves two purposes. It couples the amplified horizontal sweep pulse of current to the horizontal deflection coils, and it serves as a high-voltage auto transformer.

In *Basic Electricity*, NavPers 10086-A, it was shown that the voltage, e_L, induced in an inductance is determined as

$$e_L = L\frac{\Delta i}{\Delta t},$$

where L is the value of inductance, Δi is the change in current through the inductance, and Δt is the interval of time during which the current undergoes the change.

Because the flyback time is less than $10\ \mu s$ and both the inductance and the current change are relatively large, the induced voltage is very high. In some large-screen receivers the voltage may be as high as 30 kv. Obviously this voltage is dangerous, and care must be taken to see that the set is deenergized and that capacitor C is discharged before servicing the receiver.

During the time of the horizontal sweep the current through the output transformer builds up steadily, and simultaneously the magnetic field builds up. During the flyback time the current is reduced sharply, and the magnetic field collapses. A large voltage is thereby induced in the primary winding. This voltage is applied between the plate of the high-voltage rectifier and ground, and pulses of current flow through the rectifier during the flyback time. Because of the large number (15,750) of pulses occurring each second, a small capacitance may be used in the filtering arrangement. In commercial receivers the high voltage filter capacitor C is sometimes eliminated; filtering is accomplished by stray capacity. Likewise, series resistor R is often eliminated.

The horizontal output transformer commonly has a powdered-iron core to avoid the annoying vibrations that might be set up at the horizontal sweep frequency of 15,750 c.p.s. if a laminated core were used. Filament voltage for the high voltage rectifier is obtained from a secondary winding (one or two turns of wire) around the flyback transformer core.

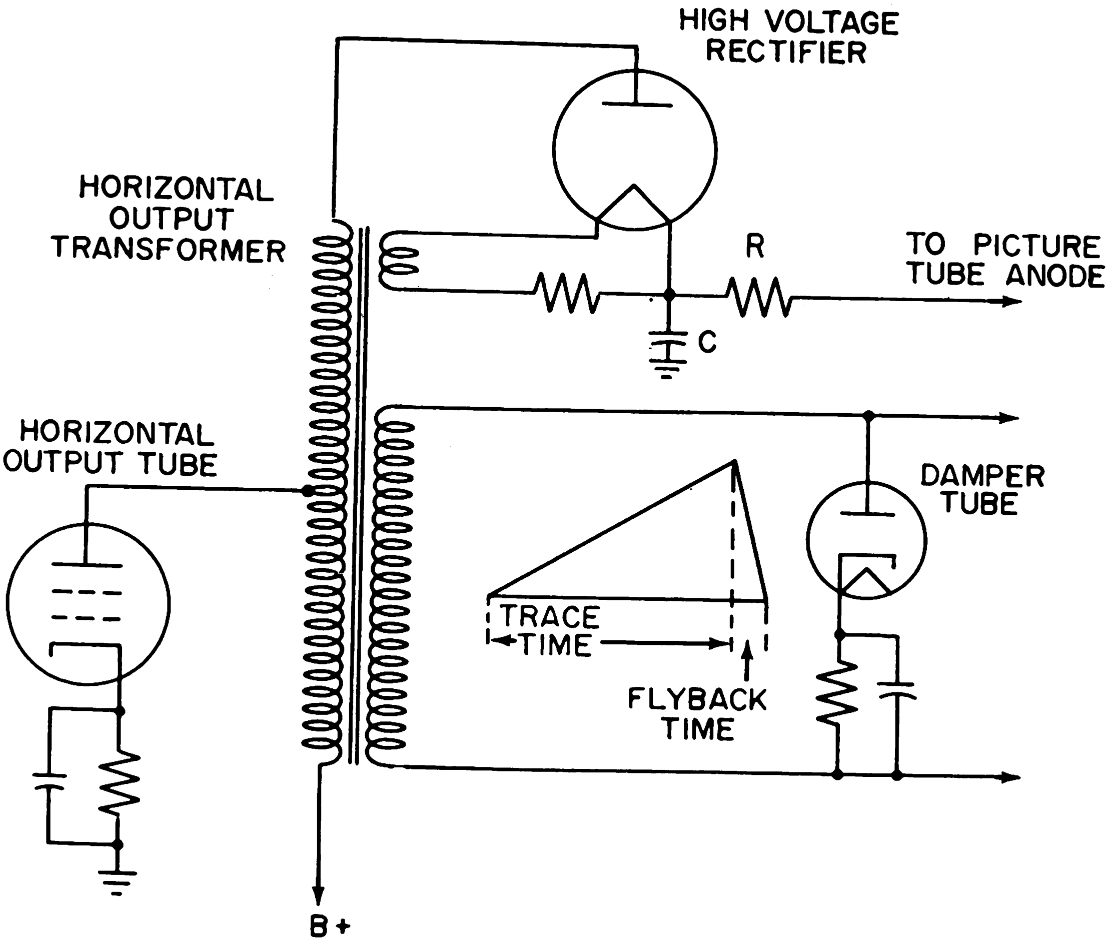


Figure 12-25. —Simplified circuit of flyback high-voltage power supply.

In this type of circuit, failure of the low-oltage supply (B+) automatically removes the gh voltage. This is an advantageous arrange-ent because if the horizontal sweep were re-oved without removing the high voltage at the me time, the screen would be burned at the oint where the electron beam strikes it.

The damper tube is used to dissipate the ergy contained in the oscillations set up in the tput stage during the horizontal flyback time. commercial sets the damper tube also serves boost the B+ voltage to a value almost twice e original B+ value. When this convenient de-gn feature is used it provides a boosted B+.

In some television sets, other types of high-ltage supplies are used. For electrostatic-e deflection tubes of small diameter, a con-ntional high-voltage supply (using a stepup nsformer, rectifier, and filter) may be used. For sets requiring higher voltages, an RF oscillator supply is sometimes used.

When very high voltages are needed, voltage doublers, triplers, or quadruplers are commonly used.

TELEVISION SOUND SYSTEMS

The sound system of a television receiver is essentially the same as that of an FM receiver. Because FM receivers are described in *Basic Electronics*, NavPers 10087, it is unnecessary to describe them in detail in this chapter. An important difference, however, is the system used for IF amplification. There are two systems in use: the SPLIT-SOUND SYSTEM and the INTERCARRIER-SOUND SYSTEM.

Split-Sound System

A simplified version of a split-sound system is shown in figure 12-26 (A). Although a large number of the newer television receivers use intercarrier sound, some sets still employ the split-sound system. In the split-sound system the sound IF is removed at the output of the converter (or from the first video IF) and amplified in a series of sound IF amplifiers.

The sound carrier is frequency modulated, and therefore it is demodulated by means of a DISCRIMINATOR. A RATIO DETECTOR or a GATED-BEAM tube may also be used. The discriminator and the ratio detector are treated in *Basic Electronics*, NavPers 10087; the gated-beam tube is explained later in the chapter. After being demodulated in the discriminator the sound signal is amplified in one or more audio amplifiers and fed to the speaker.

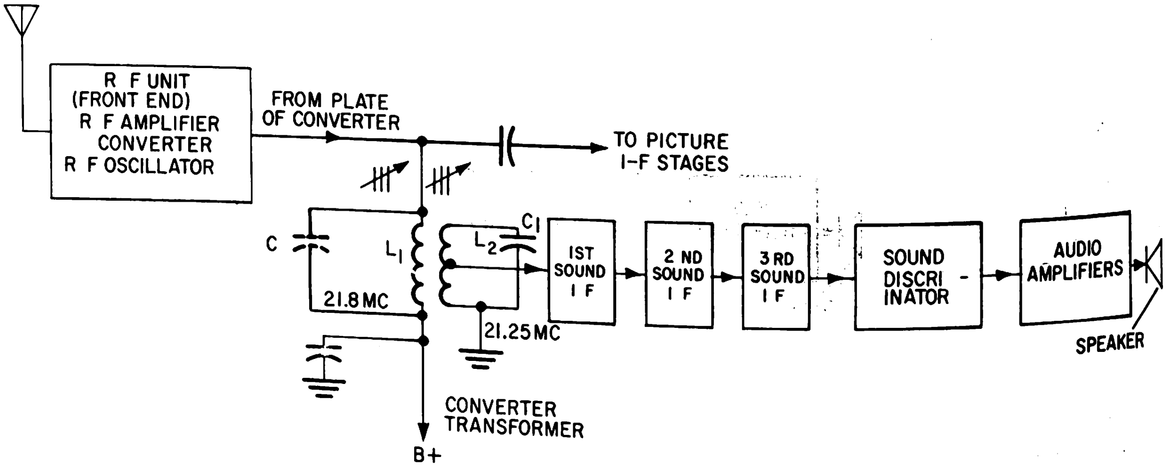
The method of removing the sound IF from the output of the converter is of interest. If the picture (video) IF is 25.75 mc. in the system shown, the sound IF must be 4.5 mc. below it, or 21.25 mc. It will be recalled that in the transmitted signal the sound carrier is 4.5 mc. above the video carrier. Therefore, if the local oscillator has a higher frequency than the incoming video and sound carriers, the sound carrier IF will be lower in frequency than the video carrier IF. In some of the newer sets the video IF is 45.75 mc. and the sound IF is 41.25 mc.

In figure 12-26 (A), L_2C_1 is a high-Q tuned circuit resonant at the sound IF frequency (21.25 mc.) and is inductively coupled to L_1. It therefore extracts the sound IF and passes it to the sound IF system.

Coil. L_1 and the distributed capacitance resonate at 21.8 mc., which is within the band pass of the stagger-tuned video IF system. As has been explained previously, none of the video IF stages is tuned exactly to the video IF. This spread in IF frequencies results in an IF band pass of about 4 mc.

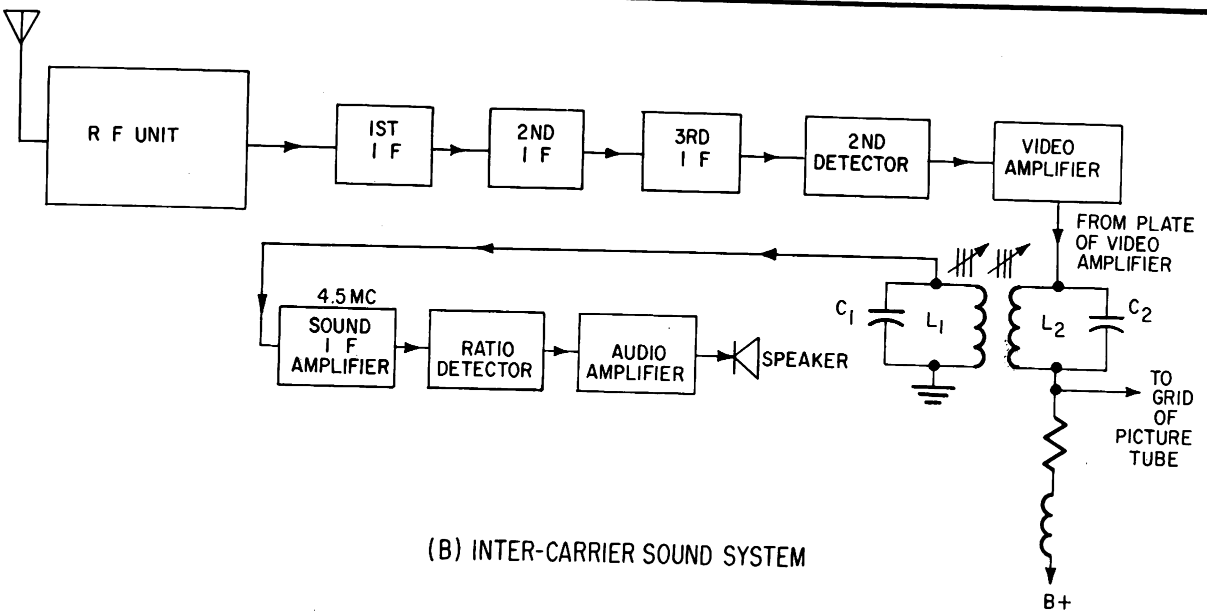
Resonant circuit L_2C_1 is a sound trap the output of which serves a useful purpose. Other traps are used in the video IF stages to remove any audio IF signals. One trap removes the lower adjacent-channel sound IF, another removes the higher adjacent-channel sound IF, and the third removes any remaining sound IF of the channel being received. If sound signals should be passed through the video IF stages, and on to the video output, the picture would be distorted; that is, horizontal bars would appear in the picture.

The maximum frequency deviation of television FM signals is 25 kc. from the carrier center frequency. In commercial FM systems the maximum frequency deviation is 75 kc. The FM band pass in television is 50 kc., and in commercial FM it is 150 kc. It is therefore relatively simple to design television sound IF stages that will pass the required band of frequencies. The IF transformers are commonly slug tuned.



(A) SPLIT-SOUND SYSTEM

Figure 12-26. —(A) Television sound system.



(B) INTER-CARRIER SOUND SYSTEM

Figure 12-26. —(B) Television sound system.

Intercarrier-Sound System

A simplified version of an intercarrier system is shown in figure 12-26 (B). This system is now used in most commercial sets. Its obvious advantage is that the sound is amplified along with the video, which means fewer audio stages are necessary.

The carrier IF in the output of the RF unit is the same as those in the output of the RF unit in the split-sound system. Because the IF stages in the intercarrier system must pass both the picture and the sound IF carrier, the band pass must be wide enough to pass both of these frequencies.

Although both video and sound IF carrier frequencies (with their sidebands) are amplified in the IF stages, the sound IF is not amplified as much as the picture IF. By keeping the sound IF level much lower than the picture IF level, a 4.5 mc. beat note, containing only the modulation of the original RF sound carrier, is obtained at the second detector. This beat note is the difference in frequency between the sound carrier IF and the picture carrier IF and, in fact, is the sound IF signal after it has passed the second detector. The difference between the video and sound carrier frequencies forms the basis of the sound IF and is always 4.5 mc.

The 4.5 mc. sound IF is extracted, as shown in figure 12-26 (B), from the video amplifier by 4.5 mc-trap. The sound IF then passes through a sound IF amplifier, which also serves as a limiter. The signal is then passed to a ratio detector and to an audio amplifier and speaker.

Audio Detector

When the ratio detector is used in the sound system of a television receiver three or more tubes are required for the sound. Even more tubes are required when the discriminator is employed.

For additional economy of tubes, the GATED BEAM tube is sometimes used as the FM detector in television receivers. (It is also used in FM receivers.) Only one additional tube (output tube) is required in the audio portion of the intercarrier-sound system employing the gated beam tube because this tube amplifies and detects the signal. A simplified version of the gated-beam tube and the associated circuits is shown in figure 12-27.

The sound IF signal is applied to the grid of the tube by the series-resonant input circuit. This provides some voltage stepup. If a given potential is applied to EITHER the input grid or the quadrature grid, the plate current will not exceed a certain value even if the other grid is made much more positive. On the other hand, if the potential on EITHER of the grids is negative enough, plate current cutoff will occur no matter what potential is applied to the other grid.

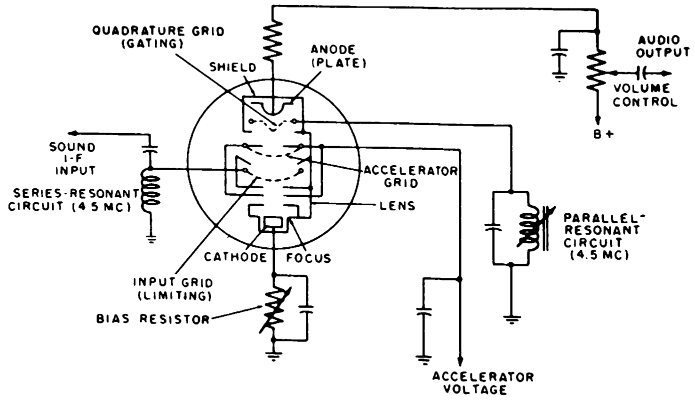
In any case, plate current will not flow unless the potentials on BOTH grids are above the cutoff value. The amount that an incoming signal is permitted to change the plate current is thus limited.

A parallel-resonant circuit, tuned to the center frequency of the sound IF, is connected between the quadrature grid and ground. This high-Q circuit is actually the heart of the FM detector.

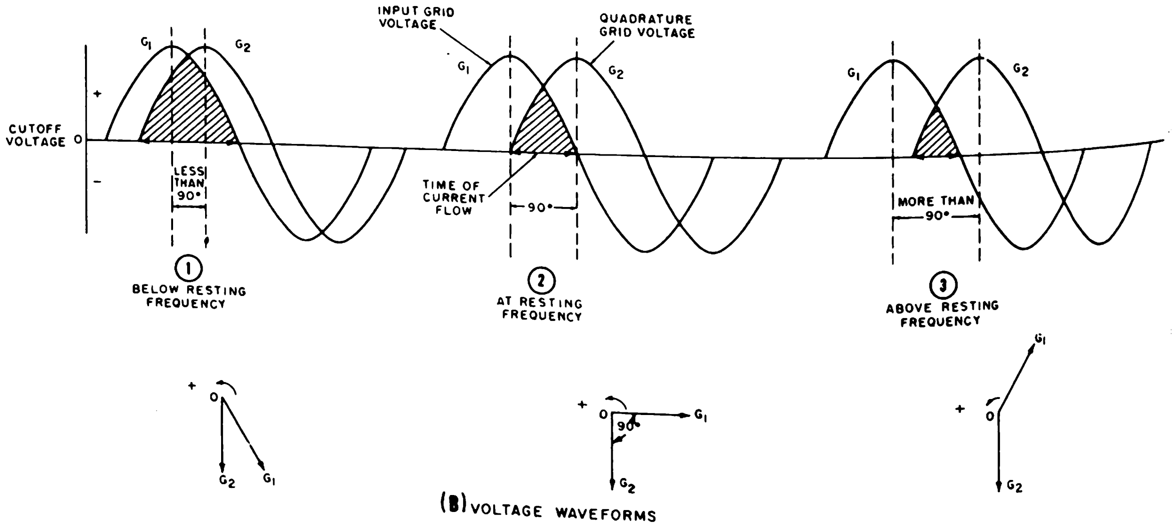
Assume that an unmodulated signal is applied to the sound IF input circuit. A voltage, the net value of which depends on the strength of the signal and the setting of the bias resistor, will be applied between the input grid and cathode. Electrons approaching the quadrature grid induce a current in the parallel-resonant circuit. The resultant voltage between the quadrature grid and ground is 90° out of phase with the voltage between the input grid and ground (fig. 12-27 (B), part ②). Therefore, the tube can conduct only when both voltages are above the cutoff voltage.

Now assume that a frequency-modulated signal is applied to the input grid. When the input signal is below the resting frequency, the parallel-resonant circuit will become inductive. The quadrature grid voltage will then be less than 90° out of phase with the input grid voltage, as shown in figure 12-27 (B), part ①.

When the input signal is above the resting frequency the parallel-resonant circuit will become capacitive. The quadrature grid voltage will then be more than 90° out of phase with the input grid voltage, as shown in figure 12-27 (B), part ③



(A) CIRCUIT



(B) VOLTAGE WAVEFORMS

Figure 12-27. —Gated-beam tube and circuit.

Because plate current flows only when there is a positive potential on the quadrature AND the input grid, the relative time durations of current flow are as indicated in the figure. The volume control and the capacitor in the plate circuit, in effect, smooth out the current pulses and develop the audio signal voltage across the volume control.

SUMMARY

Television is becoming increasingly important in several Navy applications. It is therefore necessary that the AT become acquainted with this important branch of electronics. In the study of television a good working knowledge of the fundamentals of electricity and electronics is absolutely essential. As in other branches of electronics, there is no substitute for the ability to "think through" a circuit and to apply "effect-to-cause" reasoning.

The objective in television is to convert light reflections from an object into equivalent electrical impulses so that with the help of control and scan circuits the image of the object may be reproduced at the receiver.

The complete details of a picture or object cannot be transmitted (with the system currently being used) simultaneously. They must be sent bit by bit in rapid sequence so that with the aid of persistence of vision the picture may be seen as a whole. This method of transmitting a picture in parts, or bit by bit, is called SCANNING. In the United States, scanning (both in the camera tube and in the picture tube) is from left to right and from top to bottom. In order to avoid objectionable flicker without increasing the horizontal scanning speed, and without increasing the band pass requirements of the composite TV signal, each of the thirty complete frames that are scanned out each second is divided into two fields. That is, during the first field every other line is scanned, and during the second field the lines missed during the first field are covered. This system of scanning is called INTERLACED SCANNING. Essentially the same net effect, as far as the viewer is concerned, is obtained by the shutter action in moving picture projectors.

In one type of camera tube the electron beam, under the influence of the deflection coils, scans across the mosaic, which is composed of minute globules of a light-sensitive compound. The individual globules have charges that are proportional to light incident on them. The electron beam neutralizes the charges, and the resultant instantaneous electron flow from the common back plate of the mosaic through a resistor develops an instantaneous signal voltage. The succession of signal voltages is amplified, and along with the blanking and synchronizing voltages, is used to modulate the video carrier wave.

Blanking voltages are used to blank out the electron beam in both the camera and the picture tubes during the horizontal and vertical retrace times. Synchronizing voltages are injected during the blanking periods to synchronize the horizontal sweeps and the vertical sweeps at the transmitter and the receiver.

Because an image may contain a vast amount of detail, a wide range of frequencies must be transmitted for satisfactory viewing. Therefore, the transmitter and receiver circuits must be capable of passing, without distortion, a wide range (about 4.5 mc.) of frequencies.

Although the audio signals are transmitted along with the video signals, the audio and the video systems are essentially separate systems. The video carrier is amplitude modulated and the sound carrier is frequency modulated.

Because the television signals present at the receiving antenna are often very weak, it is necessary to use a high-gain antenna. Because out-of-phase signals may arrive (after reflection) at the rear of the antenna, it may be desirable to use a highly directional antenna. Various types of commercial antennas are available for both the VHF and UHF bands. The UHF antennas are smaller, and therefore elaborate arrays that would be too cumbersome at lower frequencies are sometimes used.

Television "front ends" have much in common with radio front ends. However, band-pass considerations, wide tuning range, high-frequency operation, and reception in fringe areas have introduced design problems. Front ends are composed of an RF amplifier, a local oscillator, and a mixer. The cascode amplifier is a popular television RF amplifier. It produces fairly high gain and introduces very little noise. The oscillator and the mixer sections of TV receivers are generally included in separate tube envelopes in order to achieve maximum frequency stability.

A number of tuning methods are used in TV front ends. Rotary switches that connect the correct inductors and capacitors for the desired channel are often employed. In some systems the "tuned line" is used, and in others the turret tuner is used. The Inductuner, one of the few continuous tuners, tunes over the entire tuning range.

Band-pass requirements, vestigial sideband transmission, and the necessity for trapping out undesired frequencies have introduced problems in the design of video IF amplifiers. Stagger tuning is employed to obtain the desired band pass. In order to avoid overemphasizing the frequencies adjacent to the video carrier, the video IF stages are adjusted so that the video IF falls approximately half way down on the slope of the video IF band pass. Resonant trap circuits are used to absorb and dissipate the energy contained in the undesired frequencies.

The video detectors commonly employed are electron-tube or crystal diodes. The output of the detector may have a positive or a negative picture phase, depending on the way the diode is connected.

After the video signal has been rectified in the video detector, it is amplified in one or more amplifiers before it is applied to the picture tube. Because a wide band of frequencies must be passed without discrimination by the video amplifiers, they must be carefully designed. Special high- and low-frequency compensating circuits must be used to extend the approximate range of frequencies passed from 30 cycles to 4 mc. In other words, frequency distortion must be eliminated as much as possible. In order to pass the required wide band of frequencies, some form of shunt compensation or series compensation or a combination of both is used. Likewise, phase distortion must be eliminated as much as possible. Phase distortion is reduced by the proper design of the coupling circuits.

The d-c component of a pulse waveform must be restored after it has been removed by the passage of the waveform through the coupling capacitor in the video amplifier stage. It is the function of the d-c restorer to reinsert the correct d-c component at the input of the television picture tube so that the correct level of background illumination will be maintained. Diode or grid-leak restorers are the types often used.

Synchronizing circuits are exceedingly important in TV receivers. These circuits separate the sync pulses from the composite video signal, and in turn separate the horizontal from the vertical sync pulses.

The horizontal sync pulses are used to trigger the horizontal oscillator (a multivibrator or a blocking oscillator) at the correct instant to keep the horizontal sweep of the receiver in step with the horizontal sweep of the transmitter. If the horizontal oscillator does not lock-in properly, the picture will give the appearance of tearing.

The output of the horizontal oscillator is fed to a circuit (for example, a discharge tube), which gives the voltage pulse the proper trapezoidal sawtooth form. The pulse is then amplified and fed to the deflection yoke. It is common practice to utilize the inductive kick due to the horizontal flyback in the output transformer to produce the high voltage for the picture tube. The output transformer has an auto-transformer arrangement, which effectively adds the necessary additional inductance. Included in this stage is the damper tube which dampens oscillations and provides boosted B+.

The vertical sync pulses are used to trigger the vertical oscillator (a multivibrator or a blocking oscillator) at the correct instant to keep the vertical sweep of the receiver in step with the vertical sweep of the transmitter. If the vertical oscillator does not lock in properly, the picture will "bounce."

The pulse from the vertical oscillator is properly shaped, amplified, and fed to the yoke.

The two television sound systems in use are the split-sound system and the intercarrier system. In the split-sound system, the sound IF is picked off at the output of the mixer, or perhaps in the first video IF stage, and fed to the sound IF stages. The sound IF is then demodulated by a discriminator or a ratio detector and fed to the audio amplifier and the speaker.

In the intercarrier system the sound and the video signals are amplified in the same IF system of amplifiers. At the video detector, or in a circuit following the video detector, the sound IF is removed and fed to the sound IF amplifier, which also acts as a limiter. A ratio detector or a discriminator may be used as the FM detector. A gated-beam tube is sometimes used as the FM detector. When this tube is used, the sound IF stage may be omitted. After the FM sound signal has been detected it is fed to the audio amplifier and the speaker.

CLOSED-CIRCUIT TELEVISION

Closed-circuit television is employed in many Navy ships and stations. Navy service schools at Memphis, Tennessee have experimented with this method of teaching; several ships have installed closed-circuit TV for crew entertainment, education, and for operational purposes; and at least eight Navy shore facilities have or plan to have, closed-circuit Weathervision. Weathervision will be described later in this chapter.

The crew of the *U.S.S. Independence* (CVA-62) purchased and installed a closed-circuit TV system that serves some fifty standard receivers. The system is used primarily for crew entertainment, news and weather reports, and special "live" shows from the hangar and flight decks and from a TV studio. Telecasting flight operations from the flight deck has the fortunate advantage of eliminating "vulture's row", and the crew can view flight operations in safety. The 50-odd receivers used on the carrier are standard commercial types and can be used for commercial broadcasts reception as well as for closed-circuit operation.

Weathervision

Weathervision is a closed-circuit (wire transmission) TV system used to transmit weather data to remote locations, for example to many different locations on a Navy station. It provides means to convey this information visually through charts, maps, screens, and so forth accompanied by verbal descriptions of the presentation. Those at the receiving end are enabled to request information over the audio lines of the system.

Figure 12-28 shows the console of the Dage Weathervision System. The console consists of a TV camera mounted above a table, a control panel for station audio control, a monitoring screen, and three clocks. The clocks are alarms and are used to remind the operator of scheduled weather briefing. The station selector panel is used to pipe audio to stations requesting a briefing. The monitor screen displays the same picture as the remote receivers, and aids the forecaster in positioning the charts or maps under the camera.

Figure 12-29 shows how a closed-circuit system might be installed. The various ready rooms can be located in widely separated hangars, and each may represent several receivers in one hangar. Receivers may be located at any point that can be reached by coaxial cable, the only restriction being that video amplifiers are necessary for long runs. The amplifiers, described in detail later, serve two purposes—(1) they replace signal cable losses, and (2) provide for isolation between receivers.

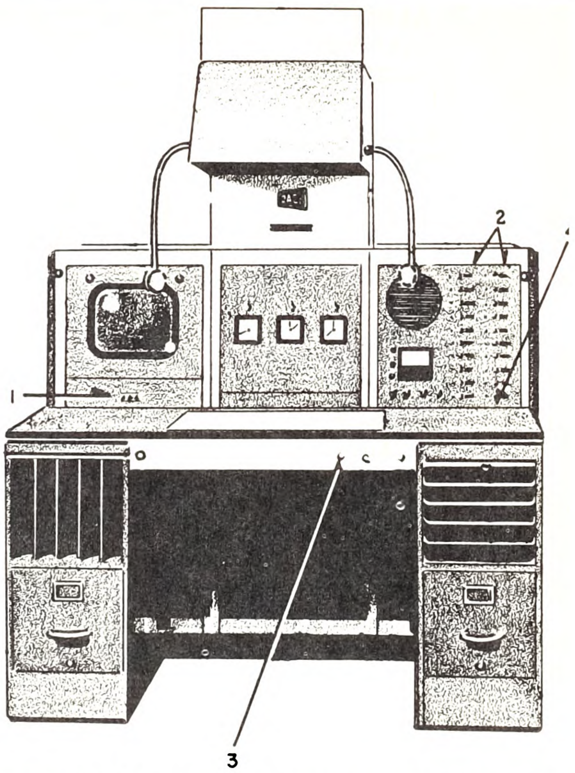


Figure 12-28.—Console of Dage Weathervision system.

1. Camera selector switches.
2. Receiver selector switches.
3. Press-to-talk switch.
4. Camera control panel.

Receivers used in the Weathervision system are much like home TV receivers; however, they are built specifically for closed-circuit operation, and will not receive standard telecast. They are also ruggedized in that their design incorporates realibility features not usually found in the highly-competitive commercial sets.

System Operation

When the weathercaster gives a TV weather briefing, he places the chart or map to be telecast on the console table. The table is a lighted transparent surface, and can be used to show either transparent or opaque material. The telecast is applied to all receivers, but the audio signal is applied only to those stations requesting it. Weather information is thereby presented visually and orally. Each receiver has a "push-to-talk" button that permits voice communication with the console operator. Should a viewer

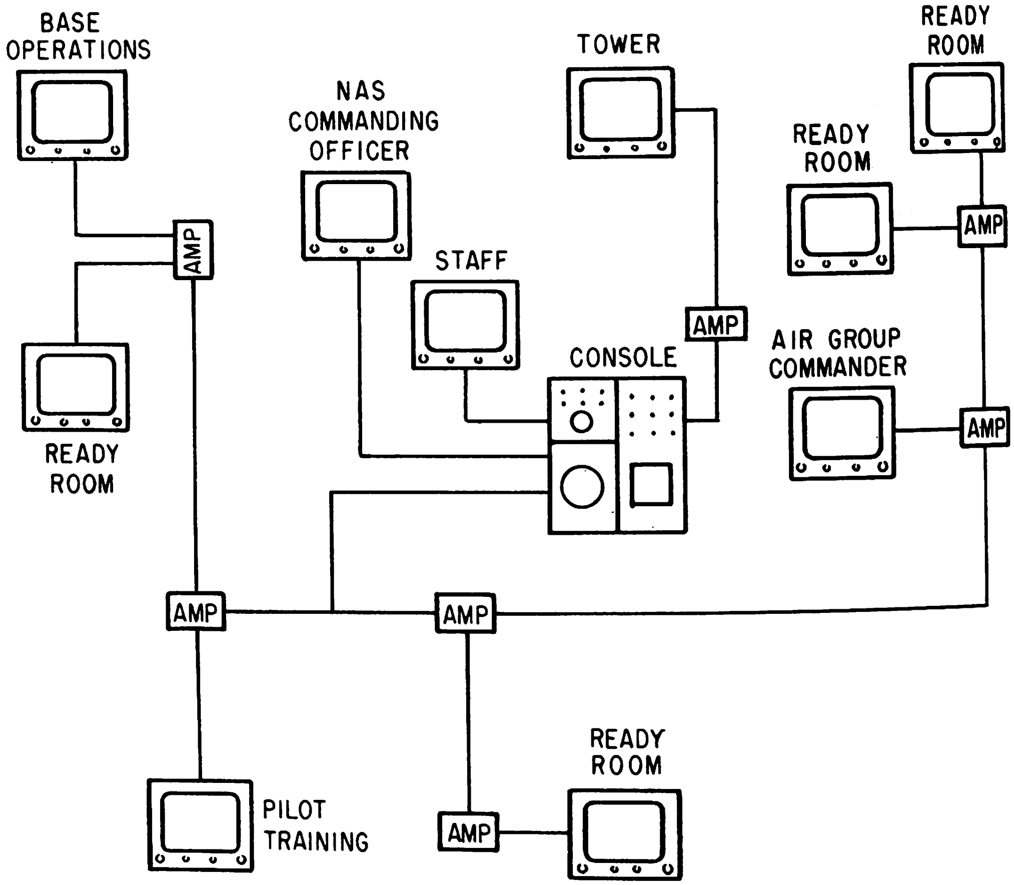


Figure 12-29.—Weathervision system.

at a remote receiver wish to hear the oral explanation of the weather material being presented, he presses the "push-to-talk" button and requests that he be included. This action also lights a lamp on the console control panel, and the console operator actuates the appropriate toggle switch to channel audio to that particular receiver. The console operator also has a tape recorder to record instructions, questions, and answers.

The theory of the pickup camera, transmitter, and receivers is basically as already described in this chapter, with the exception that the video signal is contained within coaxial cable. One problem that has not been mentioned previously is the necessity of isolating receivers from each other. When two or more receivers are served by one video line they must be isolated from each other so that no interaction occurs between them. The Dage system uses distribution amplifiers for this purpose.

Distribution Amplifiers

The distribution amplifier serves a double purpose—(1) it amplifies the video signal, and (2) it provides two isolated outputs. The two outputs are not only isolated from each other, but are also isolated from the video line.

When the switch on the amplifier is in the HIGH IMPEDANCE position (open) the video line is looped from J_1 to J_2. (See fig. 12-30.) When several amplifiers are used, all switches must be placed in the HIGH IMPEDANCE position, and the line must be terminated with an impedance matching plug. The matching plug may be eliminated if the switch on the last amplifier is placed in the 75 ohms position.

When the distribution amplifier is placed in series with the video line simply for the purpose of amplifying the signal, the switch must be placed in the 75 ohms position. The camera output is thus properly terminated.

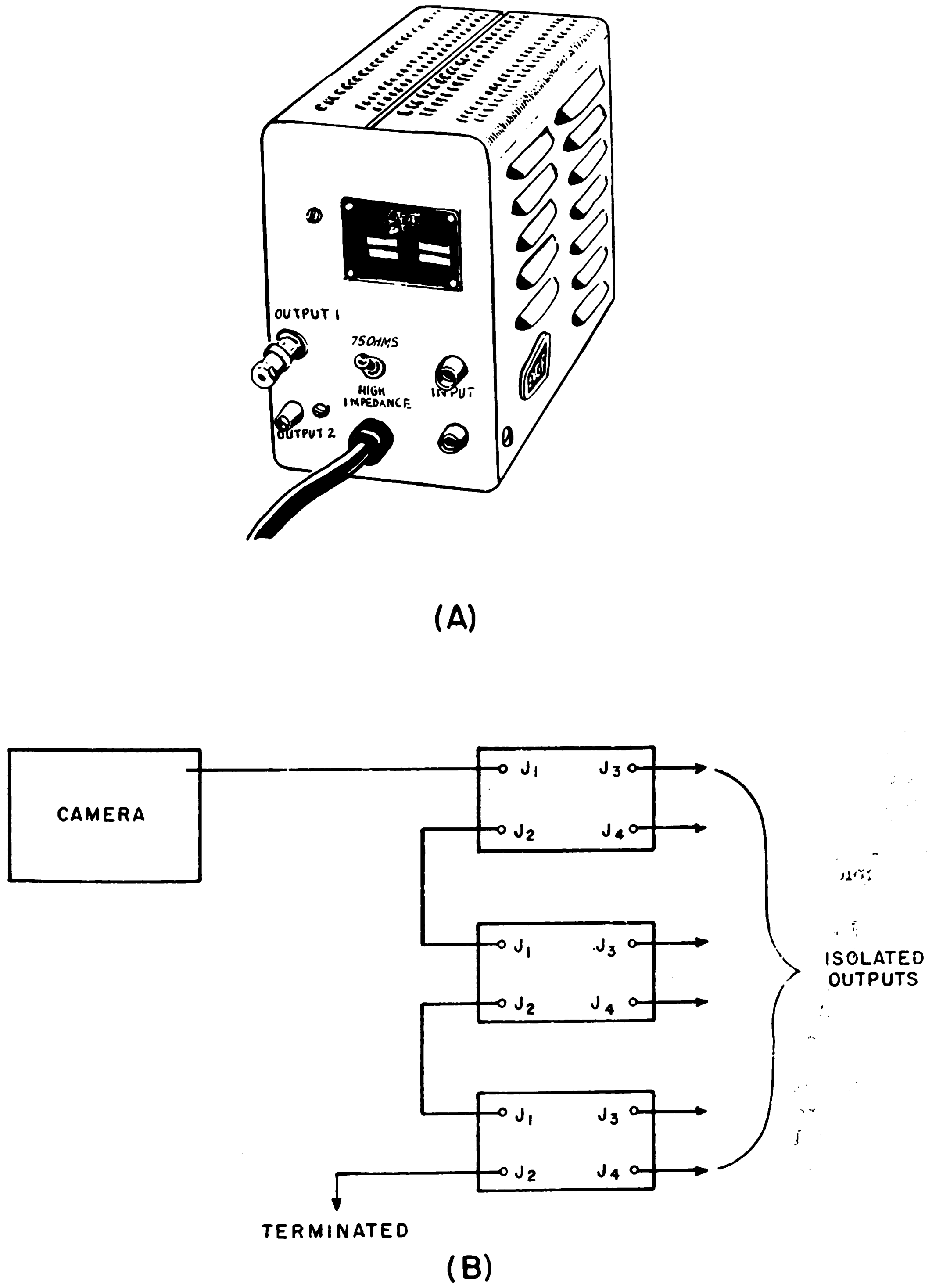


Figure 12-30.—(A) Distribution amplifier, rear view; (B) loop-through arrangement

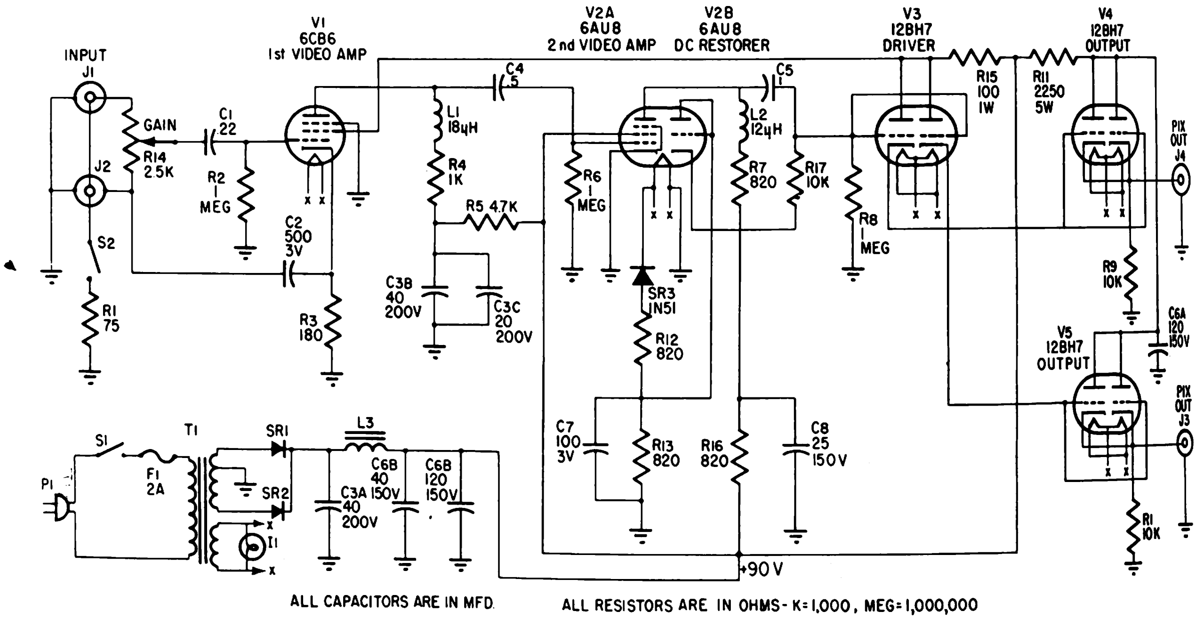


Figure 12-31.—Distribution amplifier schematic.

The video amplifiers employ low plate load resistances and shunt peaking coils for wide band amplification. Gain control R14 is adjusted for the proper signal voltage to V1's grid. (See fig. 12-31.) If too much signal is applied to V1, video compression will result. The plate signal of V1 is decoupled from the power supply by C3B and C3C.

L1 and L2 are shunt peaking coils designed to resonate with tube and stray capacitance slightly above the point where the response curve begins to fall off. The higher frequencies are thus peaked, and the response curve is flattened.

The triode section of V2 is diode-connected to provide for d-c restoration at the paralleled grids of V3. Crystal diode SR3 is connected in negative polarity across the filament voltage, and provides a small negative bias for the restorer plate. When the negative-going signal at V3's grids exceeds the plate bias on the restorer, the restorer conducts to provide a steady d-c reference at the driver's grids. Thus, d-c restoration is made.

Conductive (direct) coupling is made from the two driver cathodes to the two output tubes. This arrangement maintains the d-c signal component and provides isolated drives to the separate output stages. The output tubes, V4 and V5, have their dual triode sections paralleled. Notice that each tube has a 10-K resistor in its cathode. It is necessary, therefore, that the cathode output line be terminated in a 75-ohm impedance before normal tube current can flow.

With switch S2 set in the open position (HIGH IMPEDANCE), the input signal is coupled directly to the GAIN control in the grid of V1. With S2 in the closed position (75 ohms), the input line is terminated by R1. The two input jacks, J1 and J2, are provided so that loop-through to another circuit can be made.

AIRBORNE TV

As stated in the introduction to this chapter, TV will find extensive usage in naval aircraft of the future. Closed-circuit TV is employed in the A3J aircraft as a component of the ASB-12 Bomb Directing Set. In this application the video signal is displayed on the radar indicator. Also, the raster is composed of lines that are vertical instead of horizontal. Much of the TV circuitry is composed of circuits as already described in this chapter, but many special design features are also employed. Military standards require a high degree of reliability under conditions of changing temperature and altitude, and the stress, strain, and vibration to which any airborne equipment is subjected. The TV in the

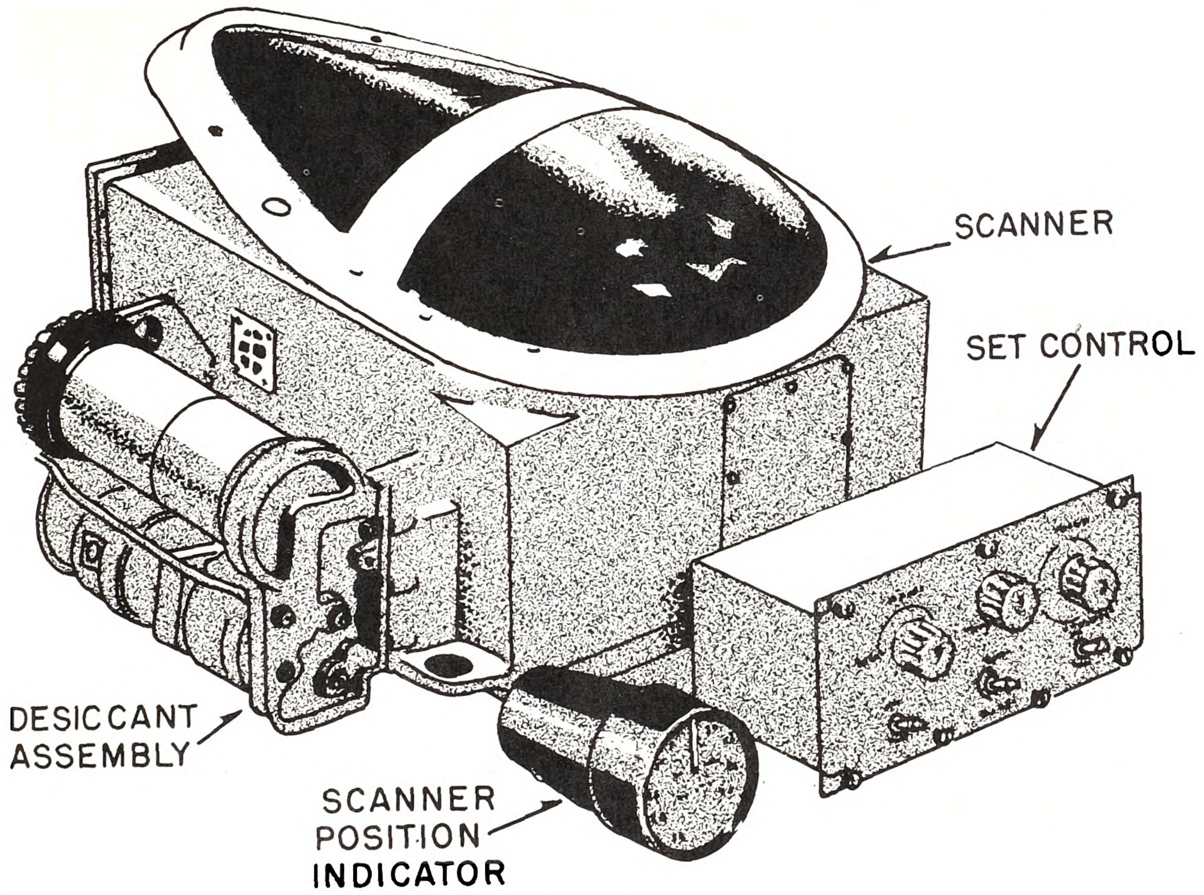


Figure 12-32. —Closed-circuit TV.

3J is ruggedized for physical toughness, and ircuit-designed for reliability. Transistors nd printed circuit boards comprise a large art of its physical construction, and the boards re arranged in racks for easy removal. Re- iability takes precedence over economy, so arts, units, subassemblies, and assemblies re designed with greater tolerances, where ermissible, and greater safety factors roughout.

The theory and operation of the closed-circuit V in the A3J is adequately covered in section I of the HMI for that aircraft. Only a few of its articulars are mentioned here, and then only r the purpose of familiarizing you with the stallation in general.

Characteristics

Figure 12-32 shows the complete closed- rcuit television system that is installed in the A3J aircraft. The scanner is mounted on the underside of the aircraft, and the TV set control scanner and position indicator are located on the navigator's panel. The desiccant assembly removes moisture from the air before it is used to cool the TV assembly.

The scanner is an optical prism that is rotated about its horizontal axis to change the elevation of its line of sight, and about its vertical axis to scan in azimuth.

The simplified block diagram in figure 12-33 shows the functional arrangement of the various units of the TV system. Servos are used to position the scanner, scanner position indicator, and the variable density filter which is called a wedge. The wedge is the unit that determines the video gain of the TV camera. Its servo receives video signals from a feedback loop. This loop is an automatic video gain arrangement. The blast filter is solenoid operated. It

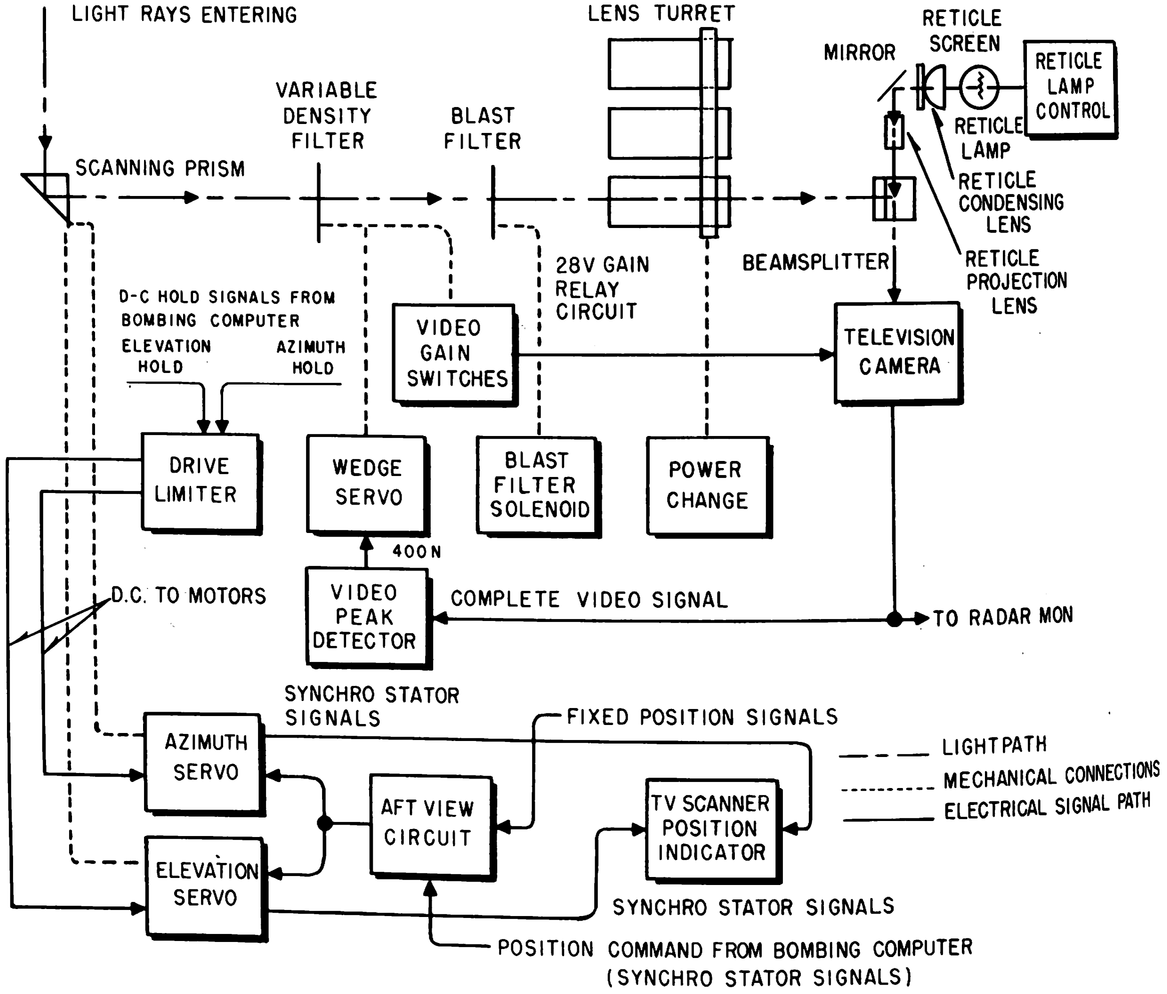


Figure 12-33.—Simplified block diagram of closed-circuit TV.

is used to protect the vidicon tube in the camera from bright light that may cause image burn. The blast filter is in the optical path at all times except when the TV scanner is in operation.

Three lenses are available in the lens turret—narrow-field, wide-field, and normal. All three lenses may be adjusted for focus. The lens turret is positioned by a power change unit that inserts the selected lens into the optical path.

The television camera is completely transistorized. It consists of nine miniature printed-circuit boards, a vidicon control unit, a 1-inch vidicon camera pickup tube, a deflection yoke, and a power transformer. The circuits involved are very similar to those described earlier in this chapter.

QUIZ

1. To reduce flicker on a TV screen, which of the following design methods was used?
   a. The interlace system
   b. Because of flyback, more than 525 lines
   c. The persistency of the screen was increased
   d. Bandpass was reduced to 4 mc.

2. Vertical and horizontal scanning on the TV screen is accomplished by use of
   a. synchronized sine wave generators
   b. synchronized sawtooth generators
   c. free-running sine wave generators
   d. free-running sawtooth generators

3. A simple dipole antenna for channel 5 with a picture carrier frequency of 77.25 mc. has an overall length of
   a. 3.03 feet
   b. 6.06 meters
   c. 30.3 meters
   d. 6.06 feet

4. Ghosts (shadows) are normally eliminated in the
   a. video detector stage
   b. video IF stage
   c. mixer stage
   d. antenna system

5. To provide sufficient band width in the video IF strip, the stages are
   a. slug tuned
   b. capacity tuned
   c. untuned
   d. stagger tuned

6. In a well-designed video amplifier stage, the high-frequency compensation network is composed of
   a. shunt peaking coils
   b. short RC filter
   c. shunt and series peaking coils
   d. series peaking coils

7. The sync separator stage is used to separate the
   a. sync (horizontal and vertical) pulses from the composite waveform
   b. vertical sync pulses from the horizontal sync pulse
   c. horizontal from the vertical sync pulses
   d. sync pulses from the audio discriminator

8. Which of the following statements is most correct?
   a. The horizontal sync pulses are shaped by an integrator circuit
   b. The vertical sync pulses are shaped by a differentiator circuit
   c. The horizontal sync pulses are shaped by a differentiator circuit
   d. Both horizontal and vertical sync pulses are distorted by the integration circuit

9. When a composite is being received, the blocking oscillator used as a vertical sweep oscillator is
   a. free running
   b. triggered
   c. synchronized
   d. all of the above

10. Automatic frequency control of the horizontal oscillator will compensate for
    a. noise pulses
    b. component tolerance drift
    c. line voltage variations
    d. all of the above

11. The trapezoidal waveform applied to the control grid of the horizontal driver tube causes plate current to vary as a
    a. trapezoidal waveform
    b. square wave
    c. sawtooth waveform
    d. sine wave

12. Select the most correct statement which concerns horizontal output circuits
    a. The damper and high voltage rectifier tubes conduct during flyback time
    b. The damper tube damps out oscillations during sweep time
    c. Only the high voltage rectifier conducts during sweep time
    d. The boost capacitor charges during sweep time

13. In the majority of television sets, if the horizontal oscillator fails, which of the following is indicated?
    a. Bias increases on the horizontal driver tube causing plate current to decrease
    b. Bias decreases on horizontal driver tube causing plate current to increase
    c. Boost B + increases
    d. Damper plate current increases

14. The sound system in a TV receiver is the same as a/an
    a. single side-band
    b. AM receiver
    c. FM receiver
    d. AM receiver on MCW

15. The more modern TV receivers use
    a. split-sound system
    b. intercarrier sound system
    c. thru-channel demodulator system
    d. nine mc. sound IF system

16. The ion trap serves to prevent
    a. electrons from forming a space cloud near the cathode
    b. electrons from forming a space cloud near the CRT screen
    c. the heavy ions from leaving the electron beam
    d. screen overbrilliance by removing the ions from the electron beam

17. Sound bars on the TV screen may be eliminated by adjusting the
    a. 4.5-mc. sound IF trap
    b. second video IF
    c. third video IF
    d. sound discriminator

18. The closed-circuit television in the A3J
    a. is utilized in heavy fog for navigation
    b. displays control signals from the controlling ship or base
    c. superimposes the TV signal on the radar signal
    d. utilizes the radar PPI as its CRT

19. The brightness is increased on the TV screen by
    a. increasing the bias on the CRT
    b. decreasing the collector-ring voltage
    c. decreasing the bias on the CRT
    d. moving the ion trap forward

20. If two pictures are observed side by side on the TV screen, the frequency of the
    a. vertical oscillator has doubled
    b. horizontal oscillator has doubled
    c. vertical oscillator is one-half the normal frequency
    d. horizontal oscillator is one-half the normal frequency

CHAPTER 13

DIGITAL COMPUTERS

Much apparent mystery surrounds the term COMPUTER. People have heard that computers are used in almost every field of science and economics to do almost everything. It is known that computers, when supplied with pertinent data, can predict political outcomes, guide missiles, determine production improvements, play games of chess and checkers, and solve mathematical problems at fantastic speeds.

How these things are accomplished will be of increasing interest to the AT of the Navy. The special-purpose airborne computer, designed to do only a limited number of jobs, is the computer of paramount interest to the AT. General-purpose computers, like Univac, are capable of many jobs; but their circuitry, while fundamentally the same as the special-purpose computer, becomes very complex.

The purpose of this chapter is to remove much of the mystery surrounding digital computers by delving into their methods of operation and by familiarizing you with the language of the science. Only the special-purpose computer will be discussed at length.

Needless to say, digital computers, like most recent "discoveries," are not new. They have been used as long as man has been holding up fingers to designate quantity. Only the methods have changed. Down through the centuries man has variously used fingers, sticks, adding machines, calculators, and now computers. The methods used by each are different, and the speed and capabilities of each are different, but the final outcomes are the same—answers based on logical calculations.

Dispel any thought that a computer can think—it cannot. Digital computers, when manufactured, are as devoid of knowledge as a doorknob. Only after some information has been placed into them can they do any calculating. A computer does not know that 2 + 2 = 4; however, it definitely has the ability to make that calculation. The ability is built into the computer by various arrangements of relatively simple circuits.

A computer also has the ability to retain information by storing it in memory banks. This information, fed to the computer by an operator, is available whenever the operator calls for it. Information in airborne computers is stored in the form of magnetic charges. Such information is stored for varying periods of time—from a few milliseconds to years—dependent upon what use is to be made of it.

When a computer performs an operation, it does so by comparing quantities representing data that have been placed into it. Its output consists of coded numbers that must be "read" and automatically translated into some form of understandable language. Since the airborne digital computer performs all of its functions by using coded numbers, it follows that any information to be fed to the machine must be transposed from plain language to coded number form. (The computer called Univac is an exception. It can accept letters as well as numbers. Those computers used in airborne equipment perform their operations using only coded numbers.)

Later in this chapter you will be taught the binary numbering system; however, the word "numbers" as applied to computers is misleading—"coded numbers" would be more descriptive of the machine language. Actually, coded numbers that represent information is merely a series of pulses and blank spaces cleverly encoded to represent various letters, numbers, items, operations, directions—or whatever is to be represented.

Anything can be represented by a code of some sort; for instance, letters of the alphabet, numbers, towns, distances. Coded messages are nothing more than letters and numbers represented in terms of something else. In a coded message, the letter A may mean originator, the number 6 may mean the letter H, etc. In digital computers, some code based on the binary numbering system is used. By employing dashes and blank spaces (binary 1's and 0's that become electrical pulses and blank spaces), various things such as letters and numbers are represented. The reason for this method of coding will become clear as you progress through the chapter.

Every item of data fed to a digital computer is assigned a coded number designation. For instance, in a given problem the letter A may be assigned the coded number 1, the letter B may be assigned the coded number 2, and so on through the alphabet. Likewise, the numbers 0-9 will each be assigned a coded number designation. The point to understand at this time is that all the information handled by airborne digital computers is in the form of coded numbers, and that these coded numbers are usually stored in the computer in the form of magnetic charges. Coded numbers, then, is the language of digital computers.

COMPUTER FUNDAMENTALS

Digital computers contain blocks of circuits and machinery that can be broadly broken down into (1) the input-output unit, (2) the memory unit, (3) the arithmetic unit, and (4) the control unit. (See fig. 13-1.)

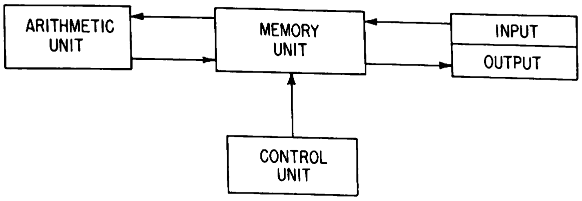


Figure 13-1.—Fundamental units of a digital computer.

The input-output unit is just what the name implies; that is, it is the unit into which information is fed to the computer, and from which information is taken out of the computer. Input information to various computers can be applied by any one of several means. Punched cards is one form used to TALK to the computer, or to feed data into it. Most Navy paychecks have perforations that, when fed to a computer, identify the check with the person involved. Magnetic tape is often used to feed data into a computer. The tape will have magnetic charges impressed along its surface in the same way that a conventional tape recorder uses tape. The tape is run through a pickup head and the magnetic charges are "read" by the computer. Other methods of feeding information to the computer's input unit are used, such as a keyboard or a magnetic drum, but they all do the same thing—feed pertinent information to the computer so that a logical solution to a problem may be obtained.

The output unit translates the result of the computer's operations into a readable language, or into some other form that is readily useful. The output of a computer may operate a relay or a light, or it may be used to position some mechanical device such as a pointer, a rudder, or a dial. In large computers the output may operate an electric typewriter.

The memory unit, called the heart of the computer, stores information until it is needed. Data fed to the computer will be directed to the memory unit. Such data includes INSTRUCTIONS that tell the computer what operations to perform. The instructions may tell the computer to direct two numbers to the memory unit, and at some later time transfer those two numbers to the arithmetic unit and multiply them together, and then place the answer back in the memory unit. When all the pertinent facts of a problem are fed to the memory unit, the instructions that follow may tell the computer to transfer these facts in a defniite sequence to the arithmetic unit and perform functions of addition, multiplication, division, and subtraction.

Feeding the pertinent data into a computer is a slow process compared to the speed with which the computer performs its operations.

Many arithmetic operations can be performed in the arithmetic unit within the space of a few milliseconds. A problem that requires 40 man-hours to accomplish by hand may be done by the computer in much less than a second.

The arithmetic unit (pronounced by accenting the MET as in CAL-U-MET') is the logical unit. It contains circuits that are relatively simple in both theory and operation. It accomplishes mathematical calculations—additions, subtraction, multiplication, and division—by performing logical operations. It must be remembered that all mathematical calculations dealing with numbers take some form of one or more of these four functions; for instance, squaring a number is merely multiplication, and extracting a square root involves a combination of all of these functions. Likewise, an exponential curve is only the connecting together of many instantaneous values that are arrived at by arithmetical calculations. The arithmetic unit experiences no difficulty in working in these areas. By comparing quantities of data against each other, the arithmetic unit is able to make logical decisions; for instance, to determine a bomb release point by considering aircraft speed, windspeed, drift, ballistics information, altitude, and other pertinent factors that have been fed to it. The solution to a given problem is sent from the arithmetic unit to the memory unit where it remains until needed for further calculations, or until otherwise routed by the control unit.

The control unit of a computer is the unit that ties all the parts of the computer together to cause them to function automatically as an integrated system. Its functions are the same as any control unit on any system in that it commands complete control over every operation the computer performs.

LANGUAGE OF THE DIGITAL COMPUTER

As stated previously, a digital computer works only with coded numbers. Each item of information fed to a computer is assigned a coded number designation, so the system of numbers employed is of paramount interest. Most digital computers use the binary numbering system—that is, the numbers 1 and 0. The reason for this choice is that in using only two numbers the computer can work at an extremely high rate of speed, and errors are reduced to a minimum. Such a numbering system readily lends itself to representing numbers by two-state switching, in which a switch is either opened or it is closed, a tube is either conducting or it is not conducting, at a given point voltage is either present or not present—in other words, a pulse or no-pulse situation.

A major advantage of a computer is its antastic speed of computation. Mechanical de-ices such as relays and switches are much too low in operation, so some other form of switch-ng is necessary if high speed is to be realized. he obvious answer is an electronic switch that orks much faster than any mechanical device. nd since numbers are to be used as the language f the computer, the question arises as to what electronic device is capable of handling ten numbers, zero through nine, efficiently. The answer—it is much easier to choose an electronic device capable of handling only two numbers and then to represent all data in terms of those two numbers.

Such a device is a vacuum tube that conducts to represent, say, a 0, and is cut off to represent a 1. A crystal diode or a transistor can do the same thing.

After the two-state electronic device was chosen as a practical switch, it became necessary to be able to represent any number in terms of 0 and 1. This is not only possible, it is easy to do. Using the binary system of numbering any number can be represented by 0 and 1.

The digits 0 thru 9 are used in our decimal system of numbers to form any quantity we wish to indicate. However, our decimal system is not the only system that can be used to indicate quantity. The decimal system employs ten digits, 0-9, but systems employing eight, seven, four, or any other number of digits COULD be used. Digital computers use only two, and the system is called the binary system.

When a number is written, like 172, it is understood that a decimal point appears after the 2 even though it is never shown. The number 172.00 is the same as 172, with no fraction indicated. Look at 172.00 again and note that the 2 occupies the first place to the left of the decimal point, the 7 occupies the second place to the left of the decimal point, and the 1 is in the third place. In our decimal system, the 2 means two 1's, and the 7 means ten 7's, and the one means one hundred 1's—or, the 2 is in the 1's place, the 7 is in the 10's place, and the 1 is in the 100's place. You were probably taught to count "units, tens, hundreds, and so forth." from the decimal. In the binary system each place from the decimal point has a definite value also, but each place represents a power of two instead of a power of ten as in the decimal system.

Figure 13-2 should help you to more easily understand the binary system, so make frequent reference to it as you read the text.

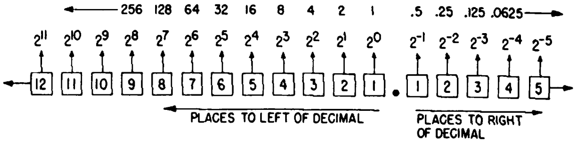


Figure 13-2.—Decimal-binary comparison.

In the figure, the PLACES to the left or right of the decimal point (called BINARY POINT in the binary system) are shown as numbered squares. Each place represents a power of 2. Thus, the number one to the left ALWAYS represents two to the zero power; place number 2 ALWAYS represents two to the first power; and all other places ALWAYS represent two to whatever power appears above them. Recall that any number to the zero power is ONE, and any number to the first power is that number itself. Thus, $2^0 = 1$, and $2^1 = 2$. The third place to the left of the binary point represents 2^2, or 4, and the fourth place represents 2^3, or 8, etc. Each place always represents the power of 2 shown in the figure, and therefore the decimal number shown above each power. Any decimal number can be arrived at by adding the proper combination of powers of 2.

The number 172 can be converted to binary in the following manner: (1) Look at figure 13-2 and see what power of 2 is the highest number that is not larger than 172, in this case 2^7 (128). (2) Place a 1 under 2^7. The 1 in this place means "pulse," and the number 128 will be added to whatever other numbers have a 1 under them when you finish this problem. (3) Moving to the right, the next lower power of 2 is 64. However, 128 + 64 is 192—too high since the number being converted is 172, so place a 0 under 2^6. The 0 means NO PULSE, and the number 192 will NOT be added to those numbers under which a 1 appears. (4) The next lower power of 2 is 2^5 (32). 128 + 32 = 160—this power (2^5) can be used since the sum of 128 and 32 is less than 172, so place a 1 under 2^5. (5) Continue moving to the right, placing 1's under those powers that can be used, and 0's under those that cannot be used to total 172.

The final outcome when 172 is converted to binary notation is 10101100, as shown in figure 13-3. Add the numbers under which 1 appears, and the sum is 172. No other combination of powers of two can make this statement! And ANY decimal number can be converted to binary in the same manner. Table 13-1 shows the ten decimal numbers in plain binary notation.

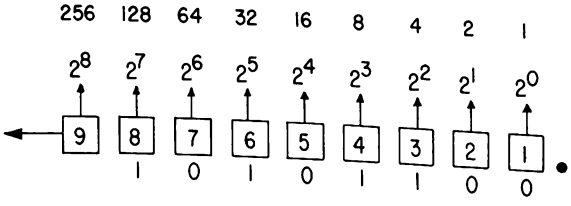


Figure 13-3.—172 in binary arithmetic.

Table 13-1.—Decimal to binary.

The decimal number	Is binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

Now consider representing a fractional number in the binary system. In figure 13-1 note that the first place to the RIGHT of the binary point is 2^{-1}, and its decimal value is 0.5 (or 1/2). The second place to the right is 2^{-2}, and its decimal value is 0.25 (or 1/4). Continuing to the right, each place away from the binary point represents the power of two and the fraction noted in the figure. The progression to the right is: 0.5 (1/2), 0.25 (1/4), 0.125 (1/8), 0.0625 (1/16), etc., in the same manner that the powers of 2 progressed to the left for whole numbers. To write the number 172.25 in binary notation, it would only be necessary to add 2^{-2} to the solution arrived at earlier. Thus, 10101100.01 is the binary 172.25. Likewise, 10101100.011 is the binary equivalent of 172.375 (or 172 3/8).

CODES USED WITH BINARY ARITHMETIC

The term "binary arithmetic," as already stated, means arithmetic using only two numbers. You have seen how any number can be written in binary notation, but so far very little has been said about the coding systems used with binary numbers. There are as many coding systems as there are types of computers; all have advantages for the particular computer with which they are used, and all have some disadvantages. Coding systems have such names as the 8-4-2-1 code, Excess-3 code, 5-4-2-1 code, and many others. The excess-3 code is one that is frequently used. But first, the reasons for coding will be given.

One reason for coding has already been mentioned—to distinguish one item of data from another. The Excess-3 code, however, means something different. Here the Excess-3 code merely means that the binary number 3 is added to any binary number that is used to designate an item of data. For instance, the letter C may be encoded in binary notation as 0011 (which is the number 3 in decimal notation). That means that when the letter C is to be fed to the computer it could be encoded to plain binary 0011. However, if the Excess-3 code is to be used with the binary numbers, then a binary 3 must be added to 0011, making it 0110 (which is 6 in decimal notation). Therefore, while 0011 means 3 in PLAIN BINARY NOTATION, 0110 means 3 in the Excess-3 code, and, in this case, it also means the letter C.

Table 13-2 will help to explain the use of the Excess-3 code.

Table 13-2.—Decimal to binary to Excess-3.

The decimal number	Is binary	And in Excess-3 code is
0	0000	0011
1	0001	0100
2	0010	0101
3	0011	0110
4	0100	0111
5	0101	1000
6	0110	1001
7	0111	1010
8	1000	1011
9	1001	1100

In the table, the binary numbers that represent the respective decimal numbers have a binary 3 added to them in order to notate them in the Excess-3 code.

The Excess-3 code (or any other code) is useful for several reasons. One reason is that by proper arrangement of circuits the computer, because of the code, can check its own calculations to see if it made an error. The main reason for using a code is that computers, in working arithmetic, must use an unusual method of calculation. Arithmetic operations are often performed by using the complement of a number instead of the number itself. This necessity is a design technicality, and further discussion on the methods of arithmetic in a computer is unnecessary for this introductory chapter. But maintenance personnel on general purpose computers must of necessity delve very deeply into that subject.

Refer to table 13-2 and note that in the binary column four binary BITS are used to change a decimal number into a binary number. The word BIT is a contraction of "binary digit," and refers to a binary 1 or 0. In writing a binary 2 or 3, only two bits are actually required—10 (one, zero) for 2 and 11 (one, one) for 3. But four bits are required to write a binary 8 or 9—1000 for 8, and 1001 for 9. For this reason, four bits are used to designate each of the ten decimal numbers, as shown in the table.

When encoding data into binary "words," it is necessary to encode letters and characters as well as decimal numbers. By using a two-bit code to precede the four-bit binary words just discussed, the ten decimal numbers, the alphabet, and several of the typewriter keyboard characters can be encoded. Table 13-3 shows how this is accomplished. (NOTE: This table is taken from *Basics of Digital Computers* by John S. Murphy. Copyright 1958, John F. Rider Publisher, Inc.)

The binary WORD is composed of an arrangement of binary BITS. Thus, in the table, 0 00 0100 is a binary WORD representing (1) the decimal number 1 in the Excess-3 coding system (2) two additional bits for the identification code, and (3) one more bit for a check pulse. Reading from right to left the word is interpreted as follows: The four-bit group (0100) is a binary 1 with a binary 3 added to it to utilize the Excess-3 code; the two-bit group (00) is used to designate the four-bit group as a numeral rather than a letter or character; and the one-bit check pulse (0) is used to make the number of pulses (1's) in the word an odd number. Considering that 1 and 0 means PULSE or NO-PULSE the check pulse is added to every word that contains an even number of pulses, and omitted from those words that contain an odd number of pulses. In this manner the number of pulses (1's) per word is always odd, and the computer can check itself for error. Should a stray noise pulse creep into the calculations, the number of pulses in a word would be even; or, if a pulse were somehow lost from the word sequence, the number of pulses would be even. In either event the computer would register an error for that calculation.

Note in the other columns of table 13-3 that the basic arrangement of the four-bit group is

Table 13-3.—Typical Excess-3 coding arrangement.

1 00 0000	0 01 0000	0 10 0000	1 11 0000
0 00 0001	, = 1 01 0001	1 10 0001	0 11 0001
- = 0 00 0010	. = 1 01 0010	1 10 0010	0 11 0010
0 = 1 00 0011	; = 0 01 0011	/ = 0 10 0011	1 11 0011
1 = 0 00 0100	A = 1 01 0100	J = 1 10 0100	+ = 0 11 0100
2 = 1 00 0101	B = 0 01 0101	K = 0 10 0101	S = 1 11 0101
3 = 1 00 0110	C = 0 01 0110	L = 0 10 0110	T = 1 11 0110
4 = 0 00 0111	D = 1 01 0111	M = 1 10 0111	U = 0 11 0111
5 = 0 00 1000	E = 1 01 1000	N = 1 10 1000	V = 0 11 1000
6 = 1 00 1001	F = 0 01 1001	O = 0 10 1001	W = 1 11 1001
7 = 1 00 1010	G = 0 01 1010	P = 0 10 1010	X = 1 11 1010
8 = 0 00 1011	H = 1 01 1011	Q = 1 10 1011	Y = 0 11 1011
9 = 1 00 1100	I = 0 01 1100	R = 0 10 1100	Z = 1 11 1100
0 00 1101	1 01 1101	1 10 1101	0 11 1101
0 00 1110	1 01 1110	1 10 1110	0 11 1110
1 00 1111	0 01 1111	0 10 1111	1 11 1111

repeated in each, but the two-bit code that precedes each four-bit group is different in each column. Choose a decimal number at random—say, the 7—and lay a ruler across all four columns. The binary 1010 is also the basic group designation for the letters G, P, and X; but the two-bit group preceding the four-bit group in each column identifies it as to its particular designation.

Note also that typewriter characters are identified in a similar manner. In airborne digital computers the coding will designate those quantities or data that are involved in the specific problem for which the computer is used.

Another feature of the coding arrangement of table 13-3 is that each successive decimal number and alphabetical letter is coded to be one binary number higher than the one that precedes it. This allows for easy sequential arrangement of operations by the computer.

Those words in the table that are not shown as being used (top and bottom of the columns) will be utilized for control functions within the computer system.

FUNCTIONS OF ELEMENTS

In the introductory passages of this chapter certain terms and elements were mentioned without elaboration. Before proceeding further it will be beneficial to clarify some of those terms and elements as to their positions in the computer, their functions, and, in some cases, the time elements involved.

You know that the language of airborne computers is binary arithmetic. Now adjust to the thought that binary arithmetic is only a convenient means of encoding numbers, letters, and characters; and that binary arithmetic, consisting of 1's and 0's, is an excellent method of saying PULSE or NO-PULSE. The computer, when reading input data and performing its operations, is concerned only with the arrangement of pulses of voltage (or current). That is the method that designers have employed to cause the computer to perform predetermined operations, and also the method by which the computer performs those operations.

The storage or memory unit, the heart of the computer, can have any one of several forms. In airborne computers the memory unit is often a magnetic drum (fig. 13-4), or a disk. The magnetic drum is an aluminum cylinder coated with a magnetic material. It rotates very fast under a series of HEADS. These heads are used to magnetize spots along the surface when data is fed into the computer, and to pick off data as magnetized spots cause a pulse to appear in their outputs. This action is very similar to the tape or wire recorder except that the portion of the revolving drum that passes under each head can be thought of as a ring or band of magnetic tape. In airborne computers there may be as many as 250 pickup heads spaced along the length of a drum, but the average airborne computer will normally employ less than that number. Each pickup head can be considered as a channel of the rotating drum, and data is placed into the channels by a programer.

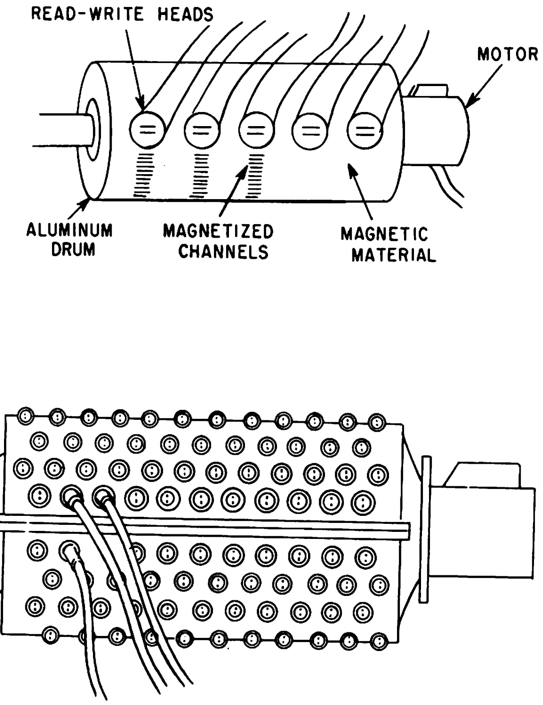


Figure 13-4.—Magnetic drum detail.

The rotating drum is the memory unit of the airborne computer in which it is used. When a problem is to be fed to the computer, pertinent data (informational and instructional) is fed to the various heads, recorded on the magnetic drum, and held there in readiness for the time when the computer is instructed to perform the operations for which that information is needed. The magnetic drum's physical dimensions will vary with the type of computer, but a drum 5 inches in diameter and 14 inches in length would be representative for an airborne computer. Along this drum there may be placed as many as 150 (or more) pickup heads.

The rotating disk used with some airborne computers is becoming more and more popular. Its function is the same as the magnetic drum, but its surface is flat like a phonograph record, instead of cylindrical like the magnetic drum.

OPERATION OF THE MEMORY DRUM

Since the computer has a magnetic memory unit that moves under heads, the information stored in the various channels can be changed as an operation progresses. That is, during the time that a problem is being solved—such as the bomb release point—some of the items of data will be varying and must be changed as the problem progresses. The heads of pertinent channels will be used to erase and rewrite information in those channels as required. To see how this is done, it is necessary to describe more fully the method employed in storing information on the drum.

Figure 13-4 shows how the channels appear on the magnetic drum. In order to place the maximum number of heads over the drum, the heads are staggered in position. The drum, made of aluminum with a coating of magnetic material, rotates at a fast speed, with a nominal spacing of 0.002 inch between it and the heads. Each channel on the drum will accommodate about eighty bits per inch. A bit, you will recall, is a binary 1 or 0. A drum 5 inches in diameter will have a circumference of about 15.7 inches, and will store 1,256 bits per channel. If 150 channels are used, a total of over 188,000 bits may be stored on the drum. If the drum rotates at 3,600 r.p.m., each bit will pass under its respective channel head every 17 milliseconds. This is called access time, or the maximum time between readings of any one bit.

Each channel on the drum is identified, and each place (address) of a bit or word is identified. The channel may be thought of as resembling a motion picture film, with block separations to locate a specific word or bit. The address of a specific binary word is identified as to its channel, block, and location within the block. The blocks will, of course, be very small as compared to the motion picture film.

The first three channels of the drum (sometimes more) are used as control, or clock, channels. Usually the first channel will contain a timing pulse that synchronizes the actions of the other channels. In this manner all the data on all the channels is in synchronism with the timing pulse; and if the drum varies in speed, every calculation or other operation of the computer varies accordingly. Because of this feature, drum rotation speed is not critical.

Many binary digits (bits) are recorded in each block on each channel of the drum, and since the bits pass under the head one at a time some means of identifying the start of a word must be provided. It would be useless to begin reading a word in the middle of that word. The first channels of the drum have magnetized sectors that provide for positive location of a word or digit within a word. These sectors usually contain pulses for timing, location of words or word groups, word separation, and bits within a word.

Information and instructions are placed into the various channels of the drum by a person who is known as the programer. It is the job of the programer to determine exactly the operations the computer is to perform, the exact sequence of those operations, and to prepare a program for the computer to follow.

PROGRAMING

When a special-purpose computer is to solve a problem, it must be given sufficient pertinent data with which to work. In an airborne computer pertinent data and instructions are programed on the magnetic drum. Such data will at times be specific information, such as a number that represents some item of data, and at other times will be a number that represents an instruction. For instance, the program may instruct the computer to carry out a sequence of operations as follows: (1) select a specific item from a specific location of a channel and transfer it to the arithmetic unit, (2) select another item from some other channel and transfer it to the arithmetic unit, (3) compare the two numbers, (4) place the larger of the two numbers in a specified address on a specified channel.

The program portion just described is a simple example used to show how a programer TALKS to a computer. The programer may not be concerned with the actual answer to the problem, but only that an answer will be produced and that it will be placed in the memory unit at a specified address. The computer may be instructed to perform the same operation over and over, and if any of the data changes the solution will also change. The solution to this problem will probably be used in other calculations required in the overall operation.

The programer for a computer does not necessarily need to know the mechanical or electronic theory of a computer, but he does need to know its maximum capabilities. The number of words per block, number of bits per word, number of channels, and access time are some of the items of information that the programer must know. One computer may be designed to accept words of no more than eight bits in length, while others are designed to accept more or less bits per word.

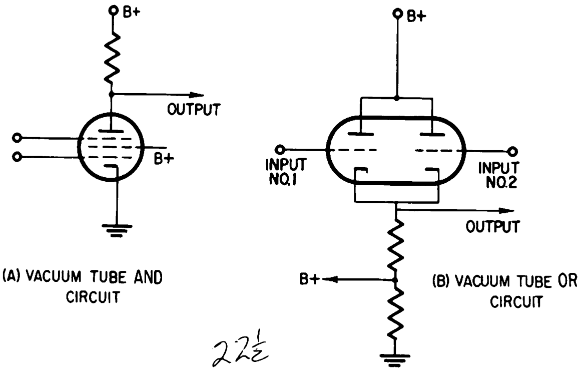
While the programer may not know the theory of computer circuits sufficiently to maintain the equipment, he will have a general working knowledge of computer methods and systems. The circuits employ storage units that may be magnetic strips on a drum, as just described, or they may be ferrite cores that operate on the same principle as magnetic amplifiers. The switching or routing system of signals in computers can be compared to a huge railroad yard where many trains are being routed through a maze of tracks. All the trains are controlled from a central point and move as directed by the controller.

A train is formed by directing an engine to move through the maze of tracks in the yard, picking up one or more cars at designated points. The completed train then moves out of the yard as an integral unit. The paths followed in forming the train were predetermined and directed in sequence by the controller. In similarity, the control unit of a computer will be the controlling device that does the switching, and the courses taken by the binary bits will resemble the tracks of the yard. In the output of the computer, the completed data will be analogous to the train.

GATING CIRCUITS

Some of the special circuits used in computers have peculiar sounding names and are called logical circuits. Three circuits used extensively are: (1) the logical AND circuit, (2) the logical OR circuit, and (3) an "inhibitor" circuit. Usually the "logical" is dropped and they are referred to simply as AND and OR circuits. These special circuits can be compared in their methods of operation to series and parallel switches. In a two-switch series circuit No. 1 switch AND No. 2 switch must be closed in order for current to flow; while in a two-switch parallel circuit current will flow if No. 1 OR No. 2 switch is closed.

The two-state devices mentioned earlier are the gates in computers. They may be vacuum tubes or solid-state devices like transistors or crystal diodes. By opening some gates and closing others, a signal may be routed over a predetermined course. The control unit determines how the gates are to be operated, and it receives its instructions from the input data. The input data, of course, is determined by the programer.



(A) VACUUM TUBE AND CIRCUIT

(B) VACUUM TUBE OR CIRCUIT

22½

Figure 13-5.—Gating circuits.

Figure 13-5 shows the arrangements for the two most common computer gating circuits. Vacuum tubes are used here, but any of the solid state devices mentioned earlier could be used. Part (A) shows an AND circuit; an input to one grid AND an input to the other grid is the necessary condition for tube conduction. When the tube conducts, its output is a negative pulse that may represent a 0; when not conducting, its output is a positive voltage or pulse that may represent a 1.

Part (B) shows an OR circuit. An input pulse applied to input No. 1 OR No. 2 will give a pulse (a 1) in the output. (Depending on design, the conducting state may represent a 1, and the nonconducting state a 0.)

In large computers literally thousands of the AND and OR circuits are used in the routing of data through the computer. By proper arrangement of the switching devices (closing and opening gates), the computer moves information in much the same manner as the train moved through the railroad yard described earlier. When a word is to be removed from an address in the memory unit and sent to the arithmetic unit, a path must be provided. Likewise, paths within the arithmetic unit itself are necessary, and finally, a path back to the memory unit and ultimately to the output unit is necessary. These paths, determined by the numerous gates, are built into the computer and operate automatically as the control unit directs an operation. The programer does not necessarily need to know the switching operations necessary for the computer to carry out an instruction; he simply instructs the computer as to what operations to perform, and the switching is done automatically.

AND CIRCUITS

An AND circuit using crystal diodes is shown in figure 13-6. Each diode is biased to cause maximum current flow when no signal is applied. Current flow is against the arrow.

Current flow from either diode through the load resistor will drop virtually all of the B+ voltage across the load resistor. Since the diodes have a very low resistance in the forward direction, the negative voltage on their cathodes appears as the output. This condition may represent a 0 in the output. Even if a positive pulse is applied to one of the inputs (No. 1 in the figure), the output is still 0, since it is connected to the negative voltage through the other diode. However, if pulses are applied to both inputs simultaneously they overcome the negative bias on both diodes, stop current flow through the load, and the output rises to B+ (a 1). The AND circuit is sometimes referred to as a coincidence circuit. The dotted lines in the figure show that any number of diodes may be connected in parallel in such a manner that all inputs must have a pulse applied simultaneously in order to change the output from 0 to 1. As soon as the pulses at the input are removed, the output returns to 0.

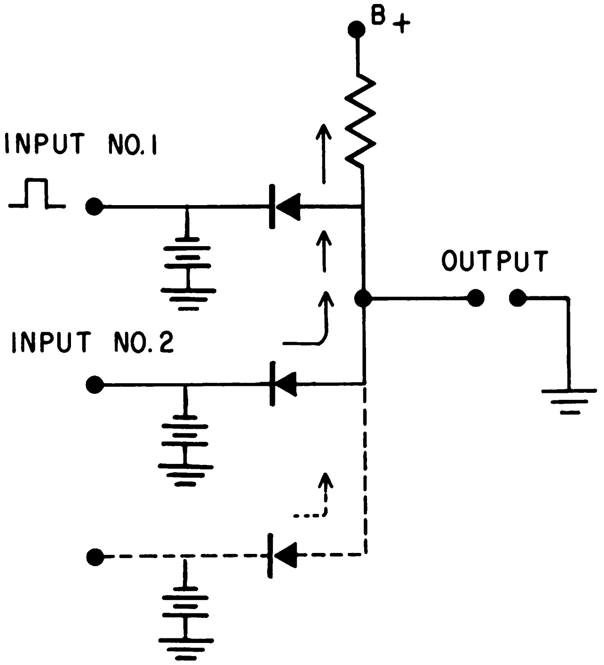


Figure 13-6.—AND circuit, using diodes.

In figure 13-7 transistors are used in cascade to provide an AND circuit. In the cascade arrangement the emitter of one transistor is connected to the collector of the next in line, in the same manner that the plate of one tube is connected to the cathode of the following tube in a vacuum tube cascade arrangement. The circuit, with no signal applied, has no current flow through the load resistor, and the output is the B+ (shown as negative polarity) which may represent a 0. In order to procure an output, all three transistor bases must have a negative voltage applied simultaneously, which permits current flow through the series-connected transistors. Current flow will drop most of the B+ across the load resistor, causing the output to rise from a negative value toward ground potential. Thus, a positive output is obtained (a 1). Should only two of the transistors have a negative pulse applied, the remaining one would still have sufficient resistance to prevent any appreciable current flow, and the output would still be negative B+. (The B+ voltage in this case may be only 1.5 volts.)

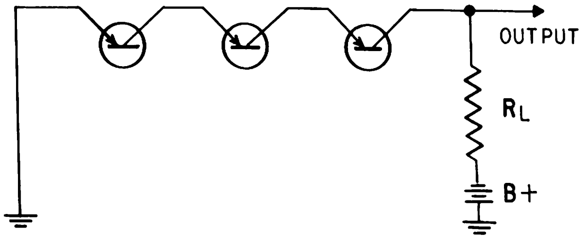
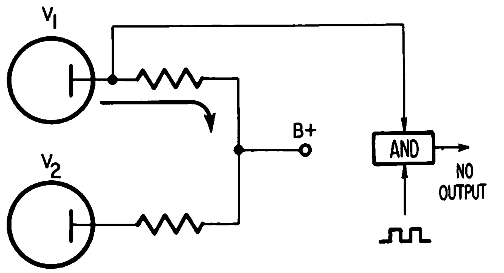


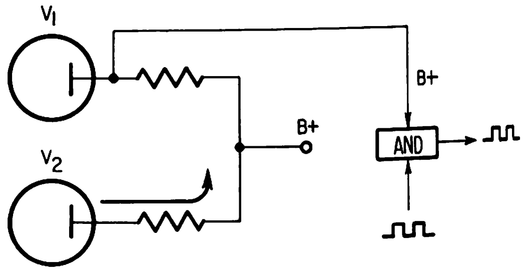
Figure 13-7.—AND circuit using transistors in cascade.

Figure 13-8 shows a method of gating by employing a steady-state d-c voltage to one input of an AND circuit. Gating in computers, as elsewhere in electronics, is a term used to describe the action of a circuit that permits a signal to go through the circuit—gate open—or blocks the signal—gate closed.

When V1 is conducting, as in (A), its plate voltage is low. Since the AND circuit requires a voltage on each of its inputs in order to open the gate, there is no output. However, when V2 is conducting, as in (B), and V1 is cut off, V1's plate voltage rises to B+, and the AND circuit has that plate voltage applied to one of its inputs. In this condition, when pulses are applied to the other input of the AND circuit, the gate is opened. In this manner a binary bit or word may be blocked or entered into the AND circuit, dependent upon the state of the flip-flop.



(A) V$_1$ CONDUCTING



(B) V$_2$ CONDUCTING

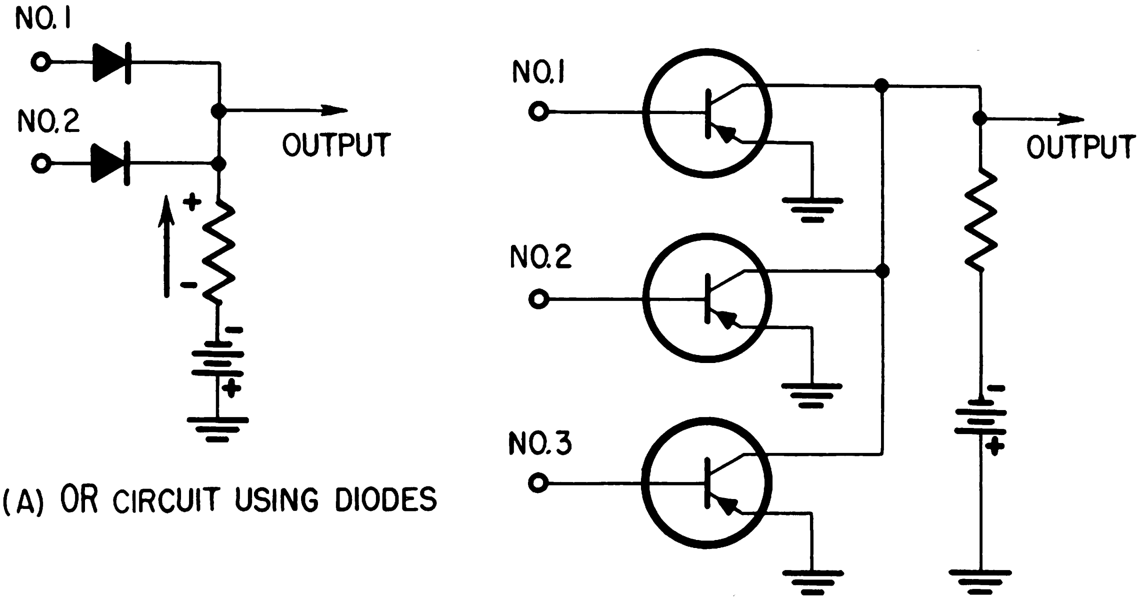
Figure 13-8.—Gating AND circuit with flip-flop.

The flip-flop in figure 13-8 will be an adaptation of the Eccles-Jordan plate-coupled multivibrator. Several types of flip-flop or two-state multivibrators are used in computers to act as switching circuits. They are used extensively in combination with other circuits to route signals and to act as counters. They can be so designed that one tube will continue to conduct until a pulse is applied to flip the conducting action to the other tube. Each time a pulse is applied to a flip-flop it flips to the opposite condition and remains until another pulse arrives. Thus, in one state its output may represent a 1, and in the other state the output will be a 0, as described in figure 13-8.

For simplicity the flip-flop shown in the figure uses vacuum tubes, but transistors are used almost universally in computers.

OR CIRCUITS

One type of OR circuit is shown in figure 13-5. The OR circuit, like the AND circuit just described, finds wide application in computers.



(A) OR CIRCUIT USING DIODES

(B) OR CIRCUIT USING TRANSISTORS

Figure 13-9.—OR circuits.

t is used where it is necessary for an output o be produced when any of the inputs have a ulse applied. Figure 13-9 shows two OR cir-uits; one uses diodes and the other uses ransistors. In (A), when a signal is applied to ither or both diodes, current is drawn up hrough the load resistor and an output is roduced. The output is a positive voltage rise rom the negative battery voltage toward ground otential. When no pulse is applied to either nput, there is no current flow; but a pulse pplied to either of the inputs causes sufficient urrent flow to produce an output.

Figure 13-9 (B) shows how transistors may e connected in parallel to form an OR circuit. utput is produced when one or more inputs ave a pulse applied. The inputs to an OR rcuit are the converging point of two or more rcuits, and the signals or pulse trains from ose circuits may be combined or added into e pulse train in the OR circuit.

INHIBITOR CIRCUIT

Figure 13-10 shows a special-purpose cir-it known as an inhibitor circuit. The inhibitor rcuit consists of an AND circuit and a NOT circuit, and its function is to inhibit or prohibit an output when the triode circuit furnishes a NOT pulse (inhibiting pulse) to the AND circuit. The NOT circuit is a phase inverter in which a positive pulse (a 1) at the grid appears as a negative pulse (a 0) at its plate; and a negative pulse at the grid becomes a positive pulse at the plate. Thus, any signal on the grid is inverted at the plate. The AND circuit is the same as

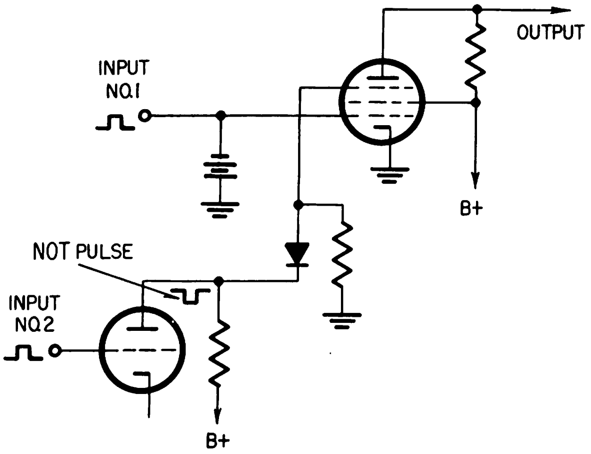


Figure 13-10.—Inhibitor circuit.

described previously, except that it works in conjunction with the NOT circuit. Although only one input for each circuit is shown, more could be employed.

The diode between the AND suppressor grid and the NOT plate serves to block B+ from the suppressor which is at cathode potential. The grid is biased to cutoff. With this arrangement there can be no output from the inhibitor unless a pulse is applied to No. 1 input. When a positive pulse is applied to the control grid, the tube conducts and an output occurs. A positive pulse applied to input No. 2 in the absence of a pulse at input No. 1 will not cause an output because (1) the pentode is held at cutoff by its grid, and (2) the inverted NOT pulse would appear as a negative pulse on the suppressor. Also, if pulses are applied to both inputs simultaneously, no output will occur because the negative pulse on the suppressor will overcome the effect of the positive pulse on the grid and prevent conduction.

The abbreviated schematics in the figures showing AND, OR, and INHIBITOR circuits do not show any components except those necessary to convey the principle of operation. Many parts, such as plate and screen bypass capacitors, have been omitted. Also, in figure 13-10, the output of the pentode is not shown connected to any following circuit, and its output pulse would be negative if the grid pulse were positive as shown. This would normally be followed by a phase inverter circuit so that the positive pulse on the grid would appear as a positive pulse in the final output.

ADDERS

The circuits shown thus far as individual circuits are all combined in the computer to operate as an integrated system. Each circuit on a schematic is normally shown in symbol form. As yet there is no standard system of symbols for computer block diagrams. The symbols taught in the Aviation Electronics School in Memphis, Tennessee, are the ones given here. In the inhibitor circuit, note that one of the inputs is terminated in a dot instead of an arrowhead. This symbol indicates that inhibitor pulses are applied to the circuit.

Adders in digital computers use combinations of AND, OR, and NOT (inhibitor) circuits to perform the functions of addition. When adding numbers, it is often necessary to CARRY a number to the next column.

$$\begin{array}{r} \textcircled{1} \\ 24 \\ +18 \\ \hline 42 \end{array}$$

In the illustration, 8 + 4 = 12 with the 1 (encircled) carried to the next column. It is the carry function of arithmetic that necessitates complex circuits in computers. Were carries not necessary, a simple OR circuit could easily add numbers, for it has an output whenever pulses appear at either or both inputs.

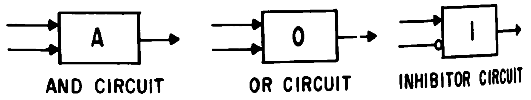


Figure 13-11. —Circuit symbols.

Pulses that form a binary word appear as a train of pulses with spaces to indicate zeroes. Thus in figure 13-12, the pulse train in (A) represents the binary digits in (B). In an adder, this pulse train applied to one input will be added to a pulse train applied to another input, as in figure 13-13. In this illustration the adder, an OR circuit, has faithfully produced an output pulse for each pulse at both inputs—but the output answer is not the correct sum of the two input binary words. The pulse train at input No. 1 is binary 101101, which is 45 in decimal notation; and at input No. 2 the binary 010011 is decimal 19. Adding 45 + 19 = 64, which should appear as binary 1000000 in the output. The error is caused by the fact that this simple adder cannot "carry" a digit. Other circuits must be used with the OR circuit to provide the means of CARRYING in addition and BORROWING in subtraction.

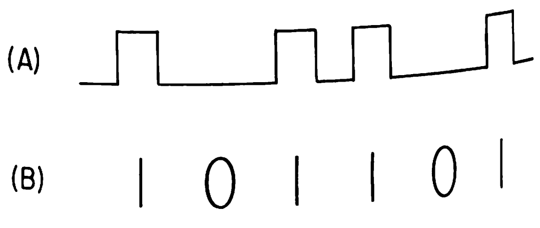


Figure 13-12. —Pulse train and binary equivalent.

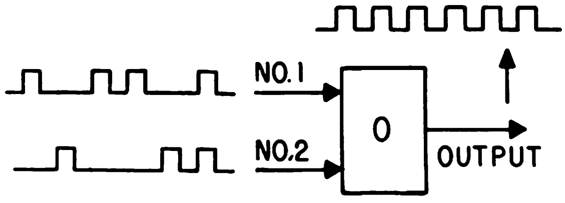


Figure 13-13.—OR adder with no carry.

One of the circuits that must be discussed in connection with adders is the delay circuit. The delay circuit functions much like a conventional delay line. It delays a pulse train for the duration of one pulse—that is, all the pulses in the train are moved one place to the left. Thus, the binary 001 applied to a delay circuit becomes 010 in its output. The delay circuit permits the carry function of arithmetic in adders. It will be combined with a combination of OR, AND, and NOT circuits to make up a full-adder circuit. A full-adder consists of two half-adders and a delay line. A half-adder is shown in figure 13-14.

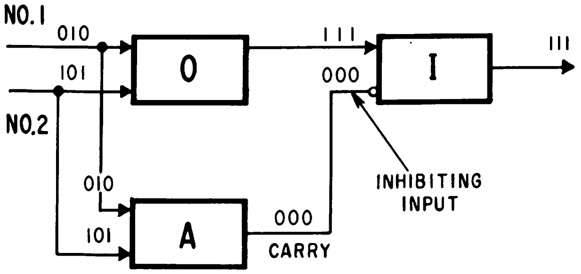


Figure 13-14.—Half-adder block diagram.

Note that a half-adder is made up of the circuits recently discussed. In schematic presentation the half-adder would appear as one block, and it would be understood to contain the circuits shown in figure 13-14. Such a circuit (the half-adder) is seldom used alone, but is combined with another half-adder and a delay line to form a full-adder, as will shortly be shown.

In the half-adder, the binary digits 010 are applied to input No. 1, and digits 101 are applied to No. 2 input. In decimal notation, 010 = 2 and 101 = 5. 5 + 2 = 7, so the binary output from the half-adder should be 111 (7 in decimal form). Recall that an OR circuit gives an output pulse whenever one or more of its inputs have a pulse applied. Note that No. 1 and No. 2 inputs have their respective binary digits applied at the same time—that is, the first digit applied to No. 1 is a 0, and the first digit into No. 2 is a 1, both digits being applied simultaneously. The next two digits into the OR circuit are a 1 at No. 1 input and a 0 at No. 2. Each time the OR circuit experiences a 1 at either of its inputs, its output is a 1. The OR circuit adds as follows:

$$\begin{array}{r}010\\ \underline{101}\\ 111\end{array}$$

111 is the true sum of the two inputs.

In this case no carry was necessary, but the AND circuit is provided to furnish a carry when necessary. As will be shown later, the AND circuit must be combined with a delay line in order to function properly. The AND circuit in figure 13-14 experiences the same two inputs as the OR circuit; however, in an AND circuit BOTH inputs must experience a pulse simultaneously in order to produce an output. Since this does not happen in this case, the AND circuit's output is 000, or, there is no inhibiting pulse applied to the inhibitor. Thus, the 111 output from the OR circuit produces a 111 in the inhibitor's output.

Figure 13-15 shows why the half-adder will not perform properly by itself. The circuit is the same as figure 13-14, except that the input digits to be added are different. Now, both inputs to the AND circuit experience a 1 simultaneously with the first digit applied, and an inhibiting pulse is produced. At the inhibitor's input the inhibiting pulse from the AND circuit prevents an output when the first 1 digit from the OR circuit is applied, and the half-adder's output is not a correct total of the two binary inputs (001 and 101).

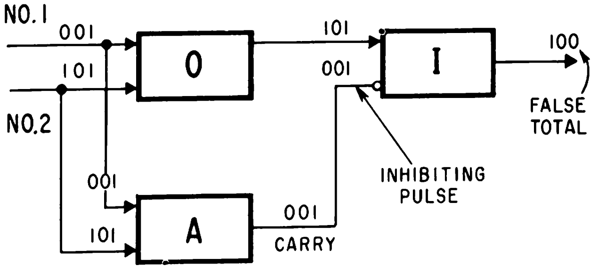


Figure 13-15.—Half-adder with a carry.

$$\begin{array}{r} ① \\ 001 \\ \underline{101} \\ 110 \end{array}$$

Binary addition is performed in this manner when a carry is involved. In the first column a 1 is to be added to a 1—the sum is 0 with a 1 carry. The 1 carry is shown encircled over the second column; adding the 1 carry to the two 0's in the second column produces a sum of 1, with no carry; in the third column a 1 added to a 0 produces a sum of 1. Then, 110 is the correct sum of the two inputs to the half-adder; but because the inhibiting pulse of the carry is in the first place instead of the second place, a false sum of 100 is produced. Another half-adder and a delay line that shifts its input digits one place to the left will correct this situation. Note in figure 13-15 that two outputs are produced from the half-adder—one is a false sum and the other is the carry. Figure 13-16 utilizes these two outputs in combination with a delay line and a second half-adder to complete a full-adder.

The first and second half-adders in the figure are identical and contain the circuits shown in figure 13-14. Figure 13-16 shows the half-adders as blocks combined with a delay line. Note that the delay line shifts the carry from the first half-adder one place to the left—this means that the 1 carry produced when adding two 1's together in the first column has been carried to the second column. The second half-adder has 100 and 010 as its inputs, and adds them to total 110. This is the true sum of the inputs to the first half-adder.

Note in figure 13-16 that a dotted line leaves the second half-adder and enters the delay line. This is a carry recirculation line. In the illustration of the carry function just finished only one carry was necessary, but any number of carry digits may be developed when adding columns of binary words of varying length. The dotted line shows that the carry number may be recirculated any number of times, each time moving the carry pulse one place to the left.

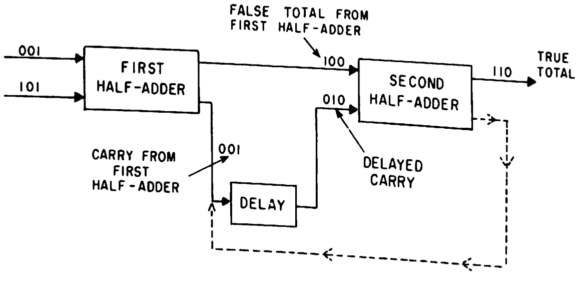


Figure 13-16.—Full-adder.

SUBTRACTING IN COMPUTERS

Subtraction in computers is performed by employing the same circuits that have been discussed; namely adders, inhibitors, and delay lines. They are not connected the same as when used in adders; however, each circuit performs its operation in exactly the manner that has been described.

Figure 13-17 shows the basic subtractor circuit. It is shown only for the purpose of showing subtraction principle; this circuit must be combined with adders and delay lines in order to function as a subtractor and give true answers. In (A) the inhibitor produces a true remainder because no "borrow" was necessary. In (B) however, the remainder is false because the basic circuit cannot perform the borrow function.

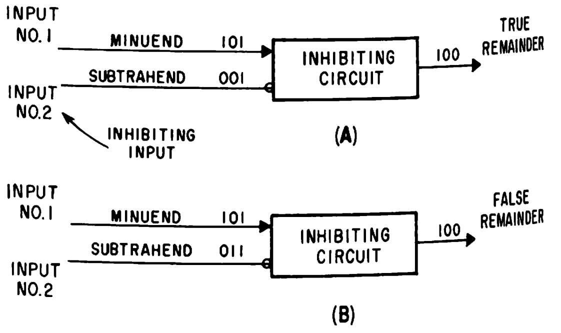


Figure 13-17.—Basic subtractor.

The subtracting circuit in figure 13-18 shows the arrangement necessary to perform a borrow function. In the following explanation it is necessary to refer to the inhibitors by number. Should you lose the train of thought sequence it may be necessary to reread the entire explanation.

In this circuit it is desired to subtract 01 from 10. At I No. 1 the inhibiting pulse in the subtrahend arrives when there is no pulse in the minuend to inhibit, so the 10 passes through the inhibitor to the adder. I No. 2 has the same inputs applied, except that they are reversed

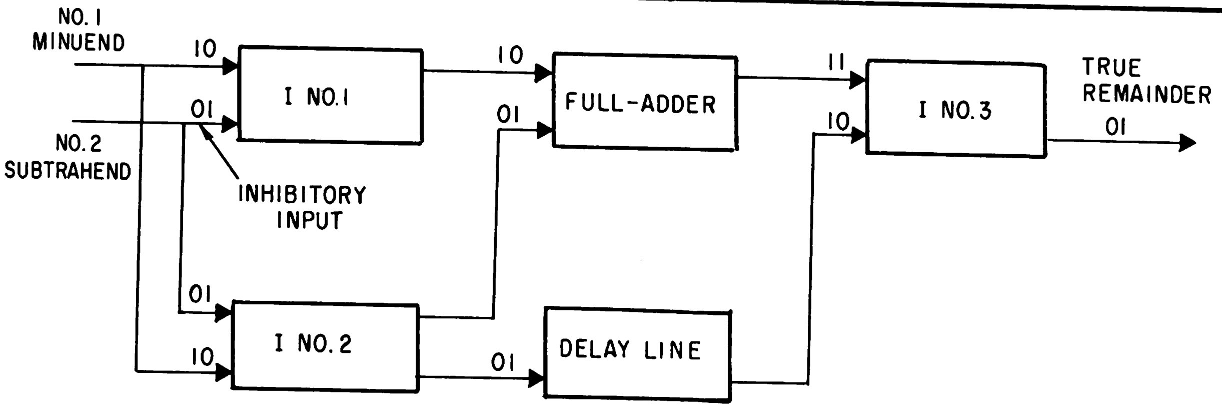


Figure 13-18.—Subtractor that borrows.

so that the minuend (10) becomes the inhibiting input. Here again, the inhibiting pulse arrives when there is no input pulse to inhibit, so the 01 input at I No. 2 is passed through and appears at two places—the delay line and the adder. At the adder, the two inputs are added to produce 11 at the input to I No. 3. I No. 3 also has an inhibitory pulse applied from the delay line which has been shifted one place to the left to become 10. This time the inhibiting pulse at I No. 3 inhibits the second pulse of the input to produce 01 at the output of I No. 3. This is a true remainder. By shifting the output of I No. 2 one place to the left, a borrow function was effectively performed.

The circuit just described is capable of performing only one borrow function. For subtraction involving multiple functions of borrow, additional adders and delay circuits are incorporated.

COUNTING BY FLIP-FLOP

The modified Eccles-Jordan multivibrator mentioned earlier is the circuit used, in conjunction with other circuits, for counting. It is a two-state oscillator that remains in either of its two conditions until a pulse is received to flip it to the opposite condition. The output, if taken from the plate of one vacuum tube, will be a positive voltage representing a 1 in one condition and a low voltage representing a 0 in the opposite condition. Each pulse input to the stage will flip it to the opposite condition, so two pulses are required at the input to produce one pulse at the output.

The simplified flip-flops in figure 13-19 are arranged to show the basic arrangement of counters. Should you require a refresher on the theory of the plate-coupled multivibrator, refer to the appropriate chapter in this course.

Counting by flip-flop is possible because of the characteristic that requires two pulses in to produce one pulse out. In the figure, note that the input to the counter chain is on the right side of the figure. This arrangement is used because the indicator lamps of each stage will be read as binary numbers, with the first stage lamp indicating a decimal 1, the second stage lamp indicating a 2, and subsequent stages indicating 4, 8, 16, and so forth. If the lamp in the second stage is lighted and the lamp in the first stage is not lighted, the binary indication is 10, or decimal 2. If both lamps are lighted the binary number is 11, or decimal 3. Additional stages are necessary to count a higher number than three, and each of these additional stages from the input represents a binary power of two in the same manner as places to the left of the binary point as described under binary arithmetic.

Note also that the grid of each tube labeled V2 has a reset provision with a positive voltage that is applied by closing the switch. Before any counting is begun, all the V2 tubes in the chain are caused to conduct by a momentary closing of the reset switch, and all indicator lamps register 0. This is the reset condition.

The grids of both tubes in each stage are jumped together so that any negative signal applied appears on both grids simultaneously. The diodes in the grid inputs prevent a positive signal from reaching the grids. They respond only to negative pulses.

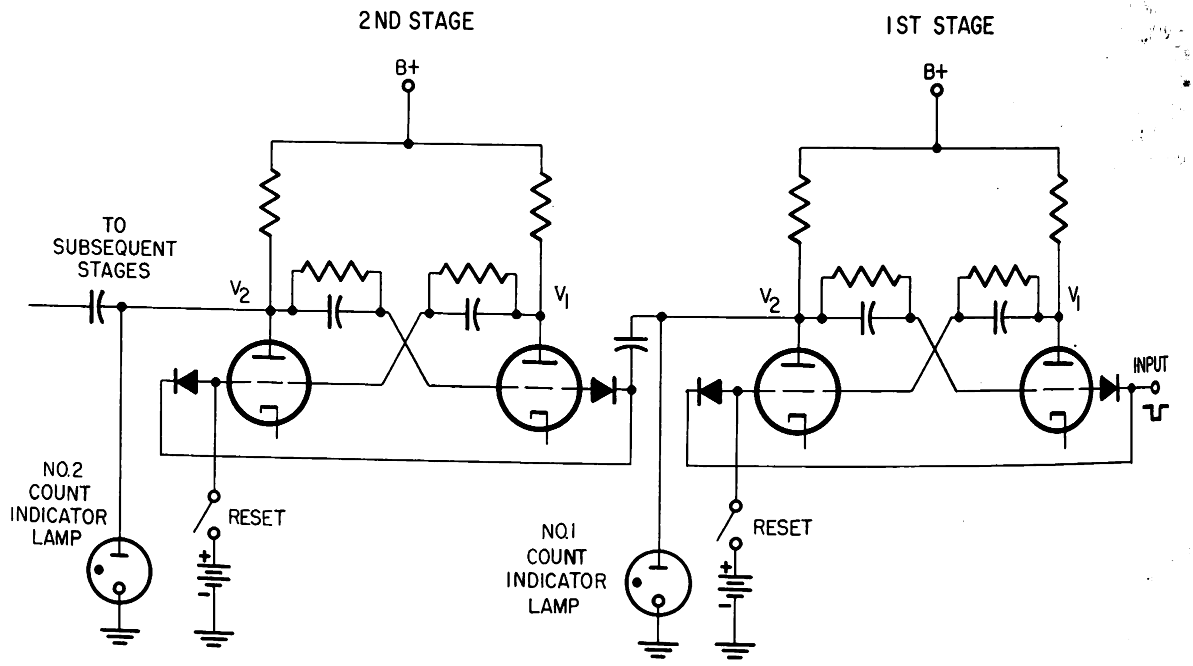


Figure 13-19.—Basic counter.

Assume that the circuit has been reset so that all V2 tubes are conducting. In this state the plate voltage is too low to light the neon lamp, and all lamps register 0. The first negative pulse applied to the inputs of V1 and V2 flips the circuit to the opposite condition; V1 now conducts, V2 cuts off, and its plate voltage rises and lights the lamp to indicate 1. The positive rise of voltage is capacitively coupled to the second stage, but the diodes prevent the positive pulse from having any effect. Reading the two indicator lamps after the first pulse has been applied produces binary 01, meaning a count of one. The second negative pulse that arrives causes the first stage to flop back to the reset state; V1 cuts off; V2 goes into conduction, its plate voltage drops, its lamp goes out; and the negative pulse is coupled to the second stage. This negative pulse flips stage No. 2 to its opposite state and lights its lamp, indicating a 2. The lamps now register binary 10, which is decimal 2. Note that two pulses were required at the input to produce one pulse out.

In late-model computers the flip-flop circuits use transistors, and a long chain of such stages can be built into a small space. Each additional stage makes provision for a higher counting capability. Each succeeding scale-of-two circuit, as the flip-flop is sometimes called, "counts" in the same manner. Each flip-flop in the figure actually divides by two, or scales by two. Each additional stage also divides by two; a two-stage flip-flop as shown in the figure divides by four; a three-stage unit will divide by eight; a four-stage unit will divide by 16, and so forth. Thus, a counter is a divider as well.

FERRITE CORE MEMORY ELEMENT

The magnetic drum has already been mentioned as a memory element. The magnetic drum in airborne computers is normally programmed for one specific problem, and is "cleared" of data after the problem is finished and before the next problem is begun. A new problem requires that new data be programmed into the drum.

Another type of memory device is the ferrite core. Its principle of operation is similar to magnetic amplifiers in that it is magnetized with a polarity corresponding to the direction of the magnetizing force. This principle and the hysteresis loop produced by magnetization are covered in *AT 3 & 2,* NavPers 10317-A. In essence, a magnetizing force applied in one direction magnetizes the ferrite core with a polarity that represents a binary 1, and when applied in the opposite direction causes the opposite polarity which represents a 0.

The ferrite core is a very small ring of magnetic material. Its outer diameter may be no more than 0.08 inch, and its inner diameter 0.05 inch.

Figure 13-20 is an enlarged drawing of a section of a ferrite core matrix. A matrix is made up of many ferrite cores—from a hundred to several thousand, depending on the computer—and connected as shown in the figure. They are arranged in a flat panel inside a frame with the wires leading out for easy attachment. The arithmetic and memory units of a general-purpose digital computer will have many of these matrices, perhaps fifty. Each core is capable of storing only one "bit" or digit, so a matrix of 250 cores will store only 250 bits. Multiplying the number of matrices by the number of cores per matrix gives the number of bits the computer can handle.

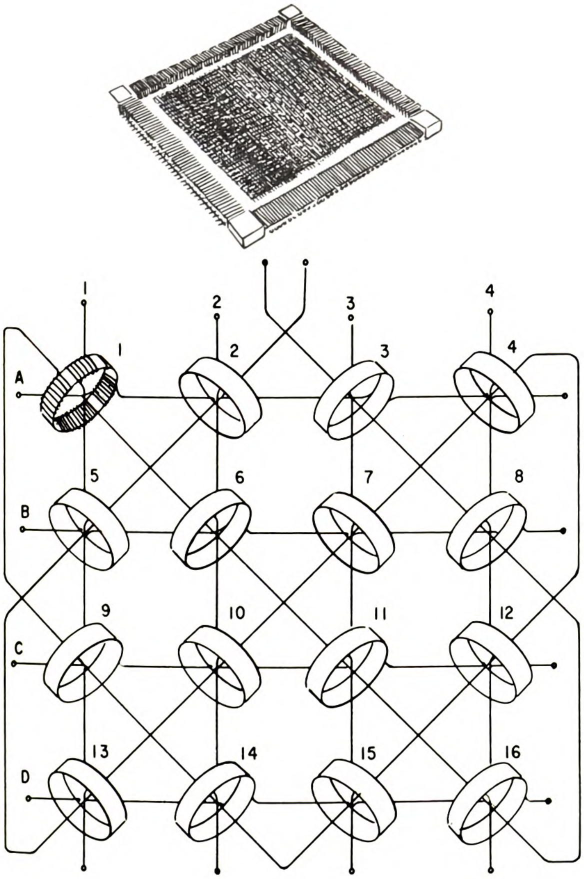


Figure 13-20.—Ferrite core memory section.

In figure 13-20 two wires cross at right angles in each core. In application, these wires are two windings around the toroidal core and are not connected. A third wire runs through each core and is common to all cores. This is the readout line. Each core has three windings on it—the two, already mentioned and the readout or "sense" winding. These sense winding senses any change that occurs in a core. The wires that cross at right angles are used to magnetize the core, a current in both wires being necessary to cause magnetization. In this manner each horizontal wire and each vertical wire intersects an entire string of cores. The only core affected, however, is the core at the intersection of both wires that have pulses applied. As an example, locate the junction of B and 2. If both B and 2 have pulses applied only core No. 6 will be affected, because the magnetizing force of only one wire is not sufficient to cause the magnetization of the other cores to flip to the opposite state. This is the system by which ferrite memory cores are magnetized and demagnetized. When the core is caused to flip from one state to the other, the polarity of the pulse picked up by the sense wire is indicative of the binary 1 or 0 that was stored in it. When the core is "read," the binary bit that it held is lost. If it is desirable to keep the bit in the core after readout, it is necessary to recirculate that bit and reapply it to the core.

Other types of storage devices are used in computers, such as the sonic delay line and electrostatic storage units, but the ones of paramount interest to the AT at this time are the magnetic drum, the magnetic disk, and the ferrite core.

THE ACCUMULATOR

The accumulator of a computer is the unit in which mathematical operations are performed. Basically, it consists of a memory section called a register, and an adder. The register is a group of flip-flop and memory elements that route and store data. The adder has been explained previously. The A-register performs the function of two registers; it stores the sum of an addition operation, and furnishes the augend to the adder. (See fig. 13-21.)

If the A-register (accumulator register) holds a number, say 4, and it is to be added to another number, say 3, then both the 4 from the A-register and the 3 from the addend register are sent to the adder. The sum of the addition, a 7, is sent to the A-register and remains until more data is to be added to it. The A-register accumulates data for arithmetic operations.

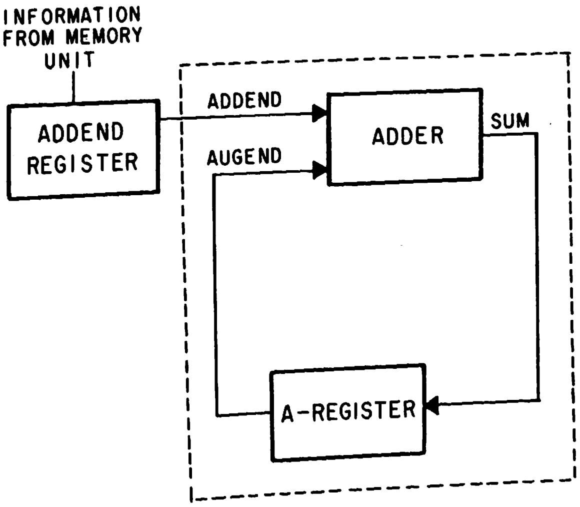


Figure 13-21.—The accumulator.

THE PROGRAM

When the programer makes a program for a computer, he programs the sequence of operations necessary for the solution of a problem. Many automatic functions are built into the computer, such as switching, counting, arithmetic operations, and others involving the special mechanics of arithmetic employed by computers. A program may be set up in such a manner that each operation is given a coded number designation, and the programer merely inserts the coded numbers as instructions to the computer. The following example is a simple illustration of instructions for the computer. Ten steps are required for the computer to solve the simple problem and each step requires an instruction. Each of the ten steps is coded with an eight-bit number; the first four bits indicate the operation to be performed, and the last four indicate the storage location of the information to be used in calculation.

The problem to be solved is:

$$\frac{(2 \times 3) - (1 + 3)}{2}$$

This simple problem can easily be solved mentally in a few seconds, and is used here only to illustrate the program by which a computer works. It is first necessary to insert each of the factors of the problem into memory positions. The factors in this problem are the numbers 2, 3, and 1. For simplicity, call the memory positions at which the factors are to be stored memory position 1, memory position 2, and memory position 3. Then the 2 factor of the problem will be stored in memory position 1, the 3 factor in memory position 2; and the 1 factor in position 3. Other memory positions may be used for storage as the problem progresses.

The program will be written as a list of eight-digit numbers. The numbers and their coded meanings are:

CODE NUMBER	ACTION INDICATED
00010001	Add the contents of memory position 1 to the contents of of the accumulator.
01000002	Multiply the contents of the accumulator by the contents of memory position 2.
01010004	Store contents of the accumulator in memory position 4.
00010003	Add the contents of memory position 3 to the contents of the accumulator.
00010002	Add the word in memory position 2 to the contents of the accumulator.
01100000	Change the sign on the word in the accumulator.
00010004	Add the contents of memory position 4 to the contents of the accumulator.
00110001	Divide the contents of the accumulator by the word in memory position 1.
01110000	Read out the word stored in the accumulator.

CODE NUMBER	ACTION INDICATED
10000000	Stop machine. (NOTE: This instruction could direct the computer to solve the same problem again.)

ANALOG-DIGITAL

Some of the inputs to a digital computer will riginate in analog computers. The program just escribed employed a group of fixed quantities— , 3, and 1. Any or all of those quantities could e variable and could change from moment to noment. If they represented altitude, compass irection, and drift, they might very well change requently and require repeated solution by the omputer. During a flight, the three variables ust mentioned will very probably originate in nalog computers. Since a digital computer only ccepts discrete quantities, the analog quantities nust be sent through an analog-digital converter nd transformed into digital form before being pplied to the digital computer. Some of the hannels on the magnetic drum will have input vires that connect to an analog-digital con- erter, and the quantities stored in those hannels will change very frequently. It is ecessary, therefore, for the computer to make ertain calculations over and over in order that ne solution may at all times be current with hanging events,

A simple problem with changing quantities ould be the question as to whether an airplane's emaining fuel is sufficient to allow it to reach given destination. Almost all factors of such a problem are variable—time, fuel quantity, airspeed, groundspeed, drift, altitude, and fuel consumption rate. The digital computer has inputs that originate at the various analog computers that measure the changing quantities. It also has a program outlined by which all the variables are considered in calculations that give a "yes" or "no" answer. The YES answer might cause a green indicator to light, and the NO to cause a red indicator to light. The computer, following the instructions of the program, constantly indicates whether the airplane can complete its mission on the remaining fuel. The necessary calculations for the entire problem will be continuingly repeated because the data for the variables will be constantly changing.

It is often necessary for the digital output to be converted to analog quantities in order to actuate a servo or some other device of an analog nature. Again, a converter is used.

DIGITAL COMPUTER APPLICATION

Digital computers will find wide usage in Navy aircraft of the future. Some aircraft now operational and others that should be operational in the near future have them installed as integral parts of a computer system. Digital computers will be employed in the navigation-weapon delivery systems of the following aircraft: A3D-2, A3J-1, and A2F-1. For information concerning these equipments, consult the appropriate technical manual prepared for the system used in each aircraft.

QUIZ

1. What is the decimal representation of the binary number 10011001?
   a. 147
   b. 153
   c. 156
   d. 149

2. The language of digital computers may be considered to be
   a. a system of numbers employed to represent information to be acted upon by the computer
   b. a special code that represents certain groups of pulses
   c. all the numbers between 1 and 10
   d. completely devoid of letters

3. The magnetization of a ferrite core in a matrix is reversed by applying
   a. pulses to all three windings simultaneously
   b. pulses to only two windings simultaneously
   c. pulses to any two winds simultaneously
   d. a pulse to the sense winding

4. An airborne digital computer accepts which of the following in its input?
   a. Letters and numbers
   b. Letters only
   c. Numbers only
   d. Pulses representing any number 0-9 only

5. The binary representation of 64 in the Excess-3 code is
   a. 1000010
   b. 1000110
   c. 1000011
   d. 1000001

6. Inputs to a digital computer may originate
   a. at analog computer outputs
   b. only from magnetic tapes
   c. only from magnetic drums
   d. only from magnetic tapes, drums, or disks

7. The timing pulse of a digital computer determines the
   a. running time for the multivibrators
   b. synchronization of data being processed
   c. open time for AND gates
   d. closed time for AND gates

8. The main reason the binary system is so important in digital computers is because
   a. it contains only two numbers and therefore is very adaptable to the flip-flop system of counting
   b. the numbers are easy to add
   c. that, due to the use of only two numbers, fewer mistakes are likely
   d. it reduces switching time and makes problem solving more rapid

9. What is the binary representation of the decimal number 17 5/16 (seventeen and five-sixteenths)?
   a. 10011.0101
   b. 10001.1010
   c. 10001.0011
   d. 10001.0101

10. In order for an OR gate to function, the input pulses
    a. may arrive one at a time
    b. must arrive at the same time
    c. must be of opposite polarity
    d. must be low amplitude positive pulses only

11. In the inhibitor circuit (fig. 13-10), an output will be obtained when
    a. positive pulses appear at both inputs
    b. either input is a positive pulse
    c. input number 1 is a positive pulse, and input number 2 is either a negative pulse or has no pulse applied
    d. input number 2 is a positive pulse, and input number 1 is either a negative pulse or has no pulse applied

12. Which of the major units of a digital computer is known as the LOGICAL unit?
    a. Control
    b. Memory
    c. Arithmetic
    d. Input

13. The flip-flop is an adaptation of the
    a. Eccles-Jordan multivibrator
    b. free-running multivibrator
    c. single-kick multivibrator
    d. cathode follower

14. What are the four major units of a digital computer?
    a. Memory, input, output, and arithmetic
    b. Arithmetic, input-output, memory, and accumulator
    c. Accumulator, control, memory, and input-output
    d. Input-output, arithmetic, control, and memory

15. A simple OR circuit would suffice as an adder for which of the following pairs of inputs?
    a. 10011101 and 01000110
    b. 10110 and 11001
    c. 011001 and 100110
    d. 001110 and 110100

16. What is the binary representation of the decimal number 72?
    a. 1001000
    b. 1001100
    c. 1000110
    d. 1100010

17. A half adder will
    a. add but not carry
    b. carry but not add
    c. serve well as a subtractor
    d. add and carry

18. A magnetic core matrix containing 250 cores can store how many binary digits of information?
    a. 125
    b. 150
    c. 250
    d. 500

19. What number would be the divisor when using a six stage binary counter as a dividing circuit?
    a. 64
    b. 32
    c. 16
    d. 6

20. An analogy could be drawn between an AND circuit and
    a. switches in series
    b. switches in parallel
    c. an inhibiting circuit
    d. three or more diodes in parallel

CHAPTER 14

ELECTRONIC EQUIPMENT AND RELATED TEST EQUIPMENT

This chapter presents information relating to late-model representative electronic equipment that will be operational during the time this training course is current. The primary objective is to introduce the equipments not as revolutionary items but as advancements in four equipment fields—communications, navigation, radar, and sonar. Some of the special-purpose test equipment associated with these electronic equipments are also discussed.

Inasmuch as *Handbooks of Service Instructions* exist for all of the equipments presented, no attempt at thorough coverage is made. Some circuits that employ new or unusual concepts are treated in detail; however, these explanations do not replace the HSI approach, but only serve as supplementary material in presenting theory of operation.

THE AN/ARC-52 UHF TRANSCEIVER

The transceiver described in this section is a representative example of military UHF communication equipment which meets the need in space-premium aircraft for increased effectiveness in smaller packages. It delivers substantially more power output than its predecessor, the AN/ARC-27. Also, it occupies only half as much space as the ARC-27, has improved reliability, and is easier to maintain.

The ARC-52 is basically an AM radiotelephone system capable of operating on any one of 1,750 frequencies with 18 preset channels. Frequency selection is by automatic control. The channels are selected by a single control located remotely from the main unit.

The purpose of the ARC-52 in an aircraft is to provide communication to ground stations, ships, or other aircraft. It operates in the range of 225 to 399.9 mc. with a rated power output of 20 watts. The receiver is a double-conversion superheterodyne; two sources are employed for producing injection frequencies. A total of 36 crystals are required for full utilization of the 1,750 available frequencies, with common use of the crystals and many of the circuits for both transmission and reception.

In addition to regular two-way voice communication, the ARC-52 has the following facilities:

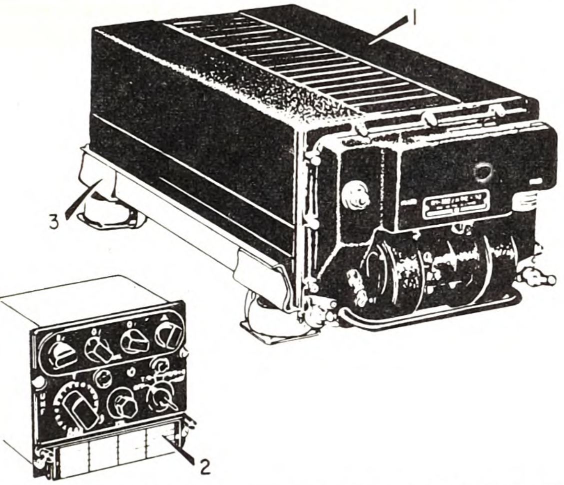
1. A fixed-tune guard receiver in the 238 to 248 mc. range.
2. Tone-modulated signals between 920 and 1,120 c.p.s. for use as emergency or direction finding signals.
3. An output for operation in conjunction with the UHF direction finder group (ARA-25).

Major Components

The physical appearance of the ARC-52 equipment is shown in figure 14-1, which illustrates the three basic components. The construction of the principal unit (the receiver-transmitter) and the control box is such that considerable reduction in weight and size has been made compared with comparable equipments. Weighing 52.5 pounds, including mount and controls, the transceiver occupies only 1.08 cubic feet. Thus, it is smaller and lighter than many multichannel UHF sets now in use; many of which have no provisions for pressurization. The latter feature, together with cooling equipment, permits operation at altitudes up to 70,000 feet.

Flexibility

The ARC-52 is designed from a modular BUILDING BLOCK approach. As indicated in figure 14-2, the set is made up of 13 subassemblies or modules; these plug into the main chassis. The modules conform in size to a



gure 14-1.—Major components of AN/ARC-52.
Receiver-transmitter. 3. Mounting MT-1477.
Radio Set Control
C-1607.

ndard of 4-1/2 by 4-1/2 by 1-1/2 inches or ne multiple thereof. Besides facilitating intenance and enabling certain economies ngineering, production, and stocking, modu- design provides great flexibility in packaging to adapt the equipment shape to specific aircraft. This feature makes the set especially applicable to Communication-Navigation-Identification (CNI) systems, such as the AN/ASQ-19, AN/ASQ-56, AN/ASQ-57, and AN/ASQ-58.

The ARC-52 modules are shown separately in figure 14-2 with the completed assembly appearing in the center. Reading from left to right in the front row, the units are as follows—guard receiver, audio amplifier, spectrum generator, receiver RF amplifier and transmitter pre-amplifier, power amplifier, and a-c power supply. Those in the back row are the fixed IF (1.85 mc.), variable IF (20-30 mc.), oscillator, mechanical tuner, modulator, relay, and rectifier.

A major advantage of the type of construction employed is the ease with which the ARC-52 equipment may be modified. Other versions of the set have been designed to function with various types of a-c/d-c primary power supply combinations. Modification of other circuitry in the equipment can be accomplished similarly, with module replacement simplifying the

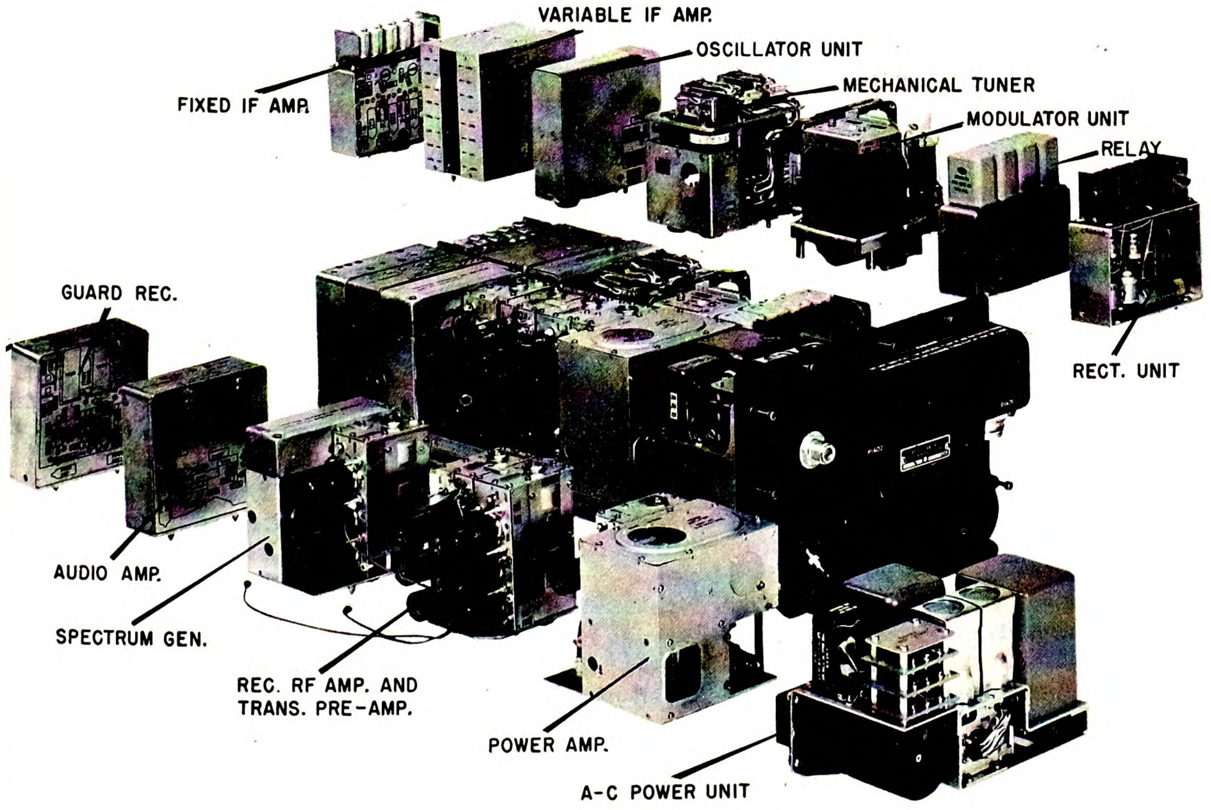


Figure 14-2.—AN/ARC-52 modules arrayed about complete radio set.

logistics problem when the equipments are dispersed over widely separated areas.

The problem of mechanical coupling between modules for tuning functions is solved by connecting the mechanical drive assembly with the appropriate modules by means of a gear-plate assembly mounted underneath the chassis. Any change in the modules involved, or the arrangement, can be easily accomplished by simple configuration changes in the gear plate. The modules have quick-disconnect mechanical couplers. Captive central elements in the couplers make removal and replacement of the module relatively simple with no synchronization problems.

In maintenance, the modular concept permits rapid replacement of defective subassemblies, which increases equipment availability. Troubleshooting is comparatively easy because of the modular breakdown and the provision of readily accessible test points.

Ease of maintenance has been one of the principal considerations in the development of the ARC-52. The objective is to permit thorough servicing with a minimum of test equipment. After removal from the transceiver, most of the modules can be operated by the use of extension cords and maintenance fixtures which enable operation and servicing of those subassemblies that require mechanical interconnection.

Operation

When operating the ARC-52, the operator has fingertip selection of any of the 1,750 available frequencies. Any of 18 preset channels or the guard channel may be selected by rotating a single channel selector control on the Radio Set Control C-1607/ARC-52, shown in figure 14-1. Other frequencies may be chosen by rotation of four manual frequency controls until the desired frequency appears on the indicator dials.

The operator also has a volume control, and a function switch which enables him to turn the equipment on and select the following functions—transceiver only, transceiver plus guard receiver, and automatic direction finder.

Another feature which simplifies the operation of the equipment is a signal-to-noise squelch system. It also has carrier-squelch provisions. The squelch circuits are disabled on the basis of the signal-to-noise ratio (understandability) instead of solely on the level of the incoming carrier wave. This eliminates the need for the operator to adjust the RF gain squelch control.

The Tuning System

Tuning of the ARC-52 is accomplished automatically by means of autopositioners and associated electrical and mechanical components. The autopositioners are motor-driven units which adjust the tuning circuits and switches of the subassemblies in the receiver-transmitter. Autopositioner tuning action is controlled by the OPEN-CIRCUIT SEEKING system, the basic principle of which is shown by the diagram in figure 14-3. When the control switch on the left and the seeking switch are set symmetrically, or with corresponding contacts occupying similar positions, there is no current path from the relay coil to ground. In this condition, the relay remains unenergized and the motor does not run. When the control switch is set to a position different from that of the corresponding seeking switch, the motor relay is energized and the motor is started. The motor continues to run until the seeking switch, which is repositioned by the motor, reaches a setting similar to that of the control switch. This arrangement stops the motor by opening the relay circuit.

A simplified functional diagram of an autopositioner unit is shown in figure 14-4 which indicates the elements controlled by the open-circuit seeking system. The principal elements involved are a motor with a gear reduction train, a slipclutch, a rotary shaft to which is fastened a notched stop wheel, a pawl which engages the notches of the stop wheel, a relay for operating the pawl and controlling the motor, and a set of electrical contacts comprising the control system.

The autopositioner (fig. 14-4) performs the following sequence during one cycle of operation:

1. The system is at rest when the control and seeking switches are in corresponding positions. The operator begins the cycle of frequency selection by adjusting the setting of the frequency selector knob.
2. The relay is energized, lifting the pawl out of the stop wheel and closing the motor contacts, thereby starting the motor.
3. The motor drives the autopositioner shaft and the rotor of the seeking switch until a position corresponding to the new position of the control switch is reached. Rotation of the motor

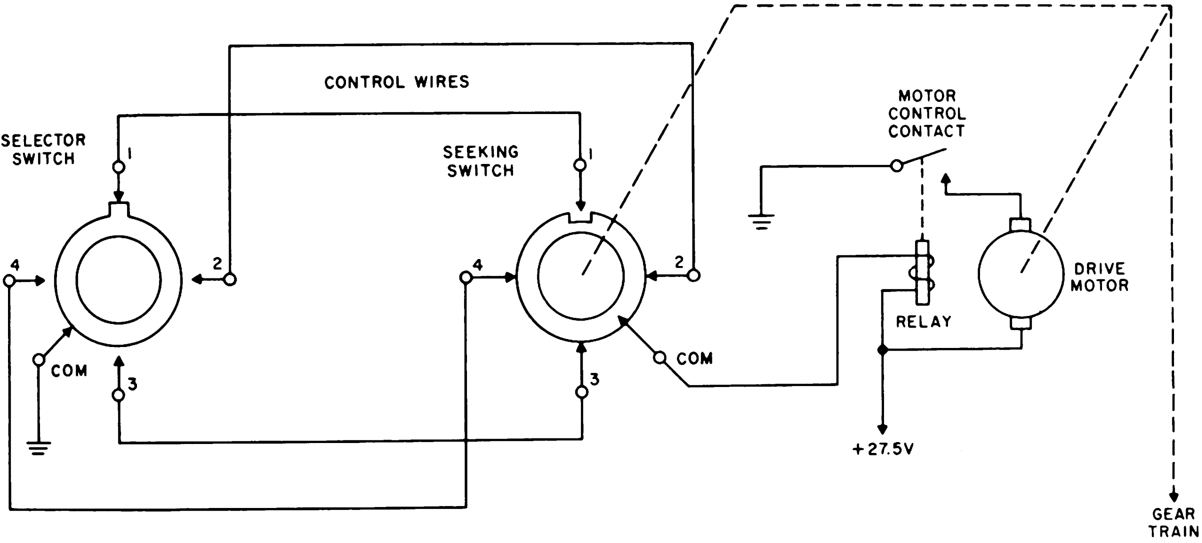


Figure 14-3. —Basic simplified automatic positioning system.

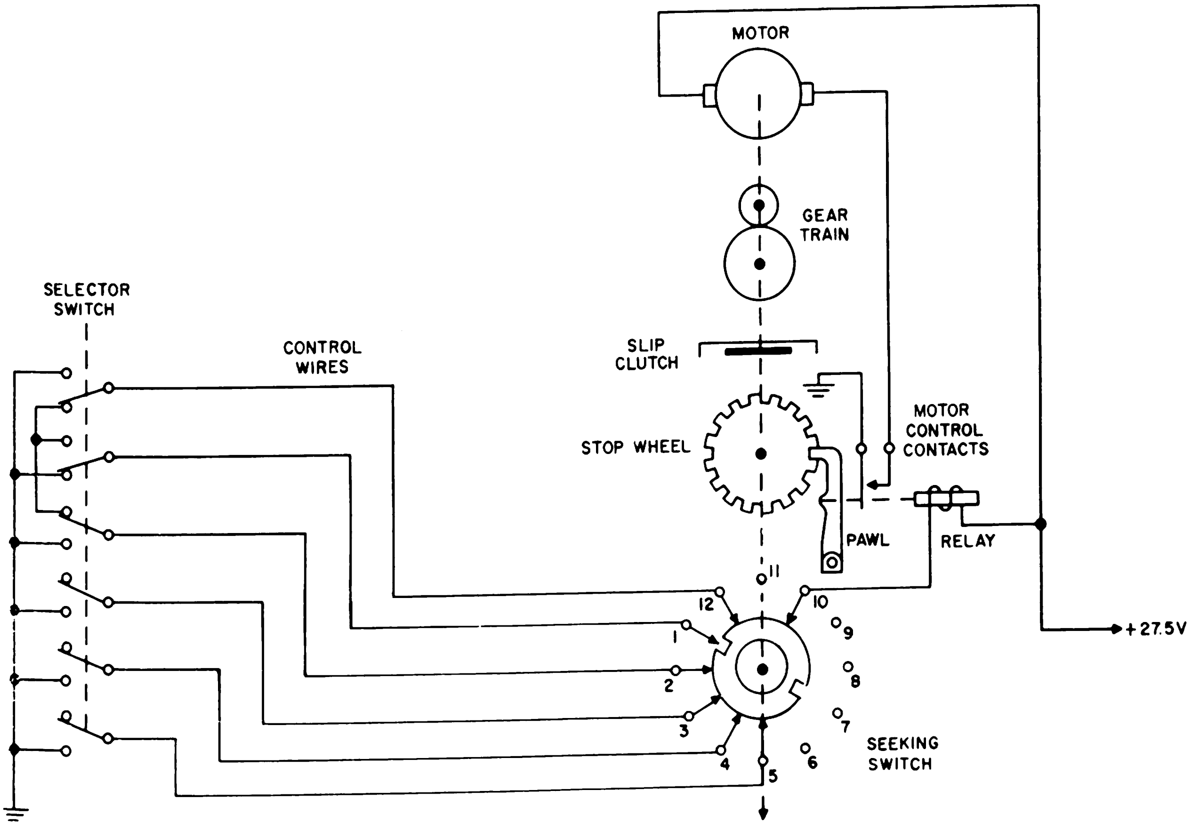


Figure 14-4. —Single automatic positioning system schematic diagram.

shaft sets various switches and tuning elements in the receiver-transmitter.

4. When the setting corresponding to the selector position is reached, the open-circuit seeking switch corresponds to the control switch. The relay circuit is then opened, the pawl engages the stop wheel, and the control shaft is brought to a quick stop. The motor coasts to a stop, dissipating the kinetic energy in the slipping clutch.

A diagram of the mechanical linkage in the tuning system of the ARC-52 receiver-transmitter is shown in figure 14-5. The drawing reveals the various tuners and switches which rotate during the operation of frequency selection. The average time required for the equipment to set up to frequency is between three and four seconds.

Power Requirements

The physical construction of the ARC-52 is of interest since it illustrates general design features which are effective in attaining improved reliability, a quality of prime importance in airborne equipment. The subassembly method of packaging and the use of miniaturized parts not only permit small size and weight but also facilitates maintenance on a subassembly substitution basis. The power requirements of the equipment are relatively low; when transmitting, it draws 375 volt-amperes, a reduction of about 20 percent of the input drawn by the ARC-27. When receiving, the supply power is 225 volt-amperes, a reduction of 40 percent.

The basic ARC-52 is a-c supplied and hence does not employ a dynamotor. An alternate a-c/d-c version contains a dynamotor which operates only during the transmit mode, thereby minimizing brush wear and other sources of malfunctions common to rotating power equipment.

Pressurization

The pressurized case of the receiver-transmitter (fig. 14-1) serves as a rugged protective cover, an effective radiation shield, and an efficient heat exchanger. The case, which

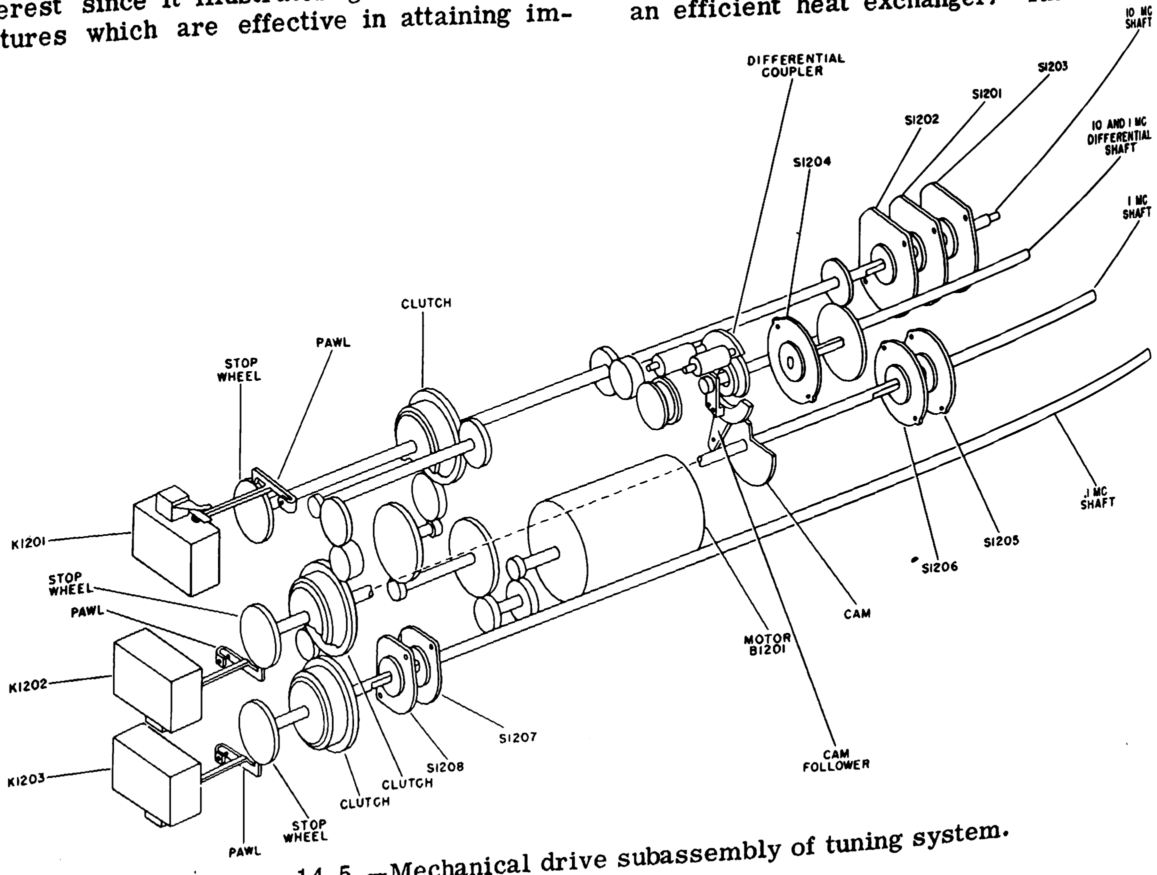


Figure 14-5.—Mechanical drive subassembly of tuning system.

des over the main chassis to make airtight ntact with the front casting, is double walled d is constructed of corrugated aluminum. r is forced into what is called the plenum amber between the walls by an external blower the transceiver's front panel. After absorb- g heat from the inner wall of the case, the r is exhausted through vents in the top of the ver. Inside the air-sealed container an axial- w blower circulates the air to improve the at transfer.

All blowers are a-c operated so that brush ar and commutator faults are eliminated. The se is designed structurally to withstand at- spheric internal pressure with complete sence of external pressure. Extra rugged- ss in the shock mounts helps to overcome the ects of the high stresses occurring in catapult takeoffs and arrested landings on aircraft carriers.

System Block Diagram

The ARC-52 system is shown in block diagram form in figure 14-6. A relay switches the signal and it goes through the amplifier in the same direction both in transmit and receive.

The ARC-52 employs double-conversion superheterodyne operation to provide maximum selectivity and sensitivity. In reception, the incoming signals are heterodyned successively in two mixer stages with injection frequencies from two separate sources to produce the desired intermediate frequencies. Conversely, during transmission a basic frequency is mixed

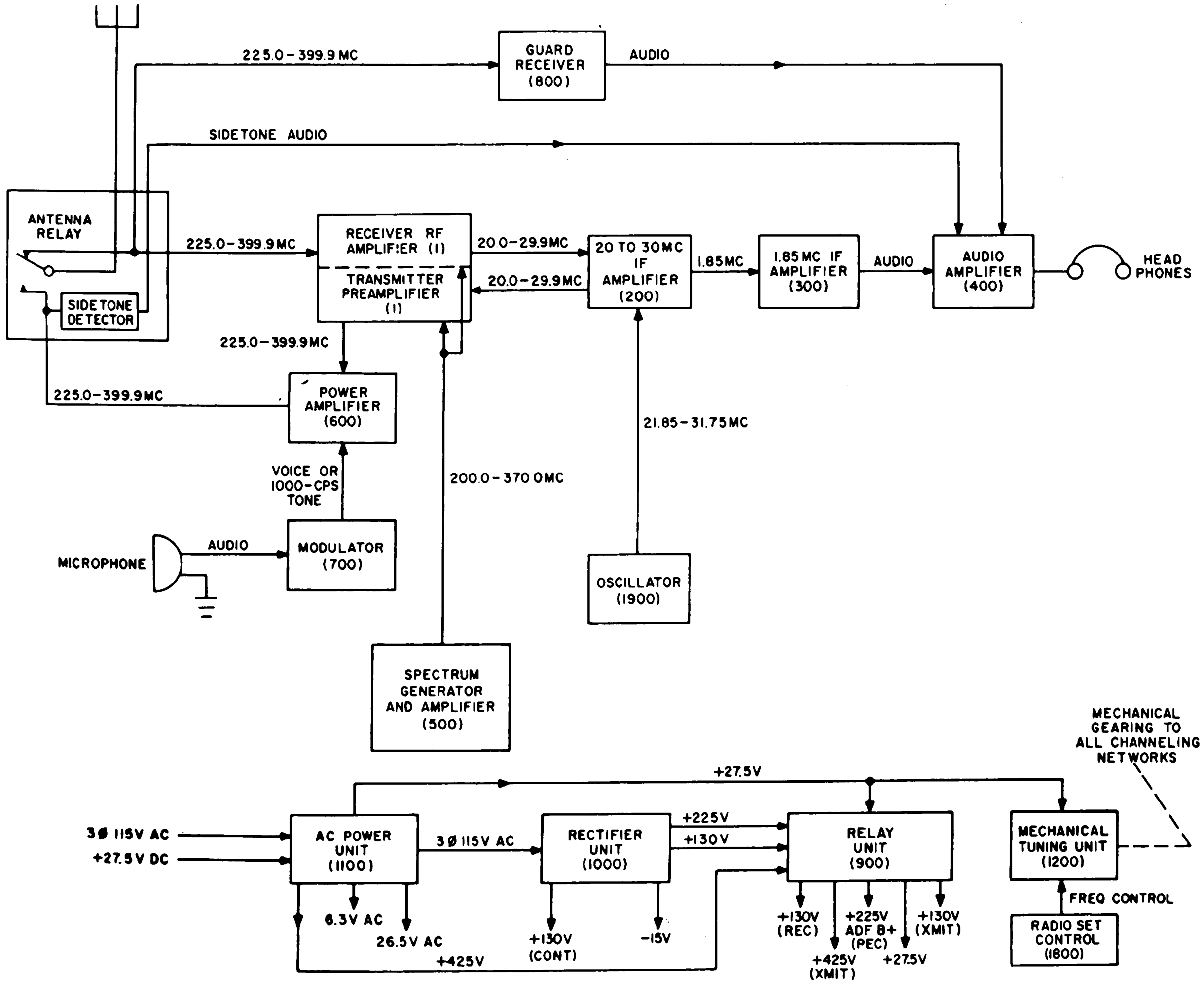


Figure 14-6.—Block diagram of the AN/ARC-52 receiver-transmitter.

with the two injection frequencies to provide a carrier in the required frequency range.

Injection signals in the 200 to 370 mc. range are derived from the spectrum generator (fig. 14-6) in which the fundamental signals are produced by a crystal oscillator, then fed through a frequency multiplication system, and amplified.

Injection frequencies in the 21.85 to 31.75 mc. range are produced by heterodyning the output of a crystal oscillator having a 24.9 to 33.9 mc. range with the output of a crystal oscillator with a 3.05 to 2.15 mc. range.

In reception, the incoming signal is fed through an RF amplifier to the first mixer, where it is heterodyned with the 200 to 370 mc. output of the spectrum generator and amplifier. The result is a 20.0 to 29.9 mc. first IF signal, which is amplified and fed to the second mixer for heterodyning with the 21.85 to 31.75 mc. injection frequency. The resulting final intermediate frequency of 1.85 mc. feeds through a filter and four stages of amplification into a silicon diode detector, where it is demodulated and fed to the audio amplifier and into the headset.

The same oscillators and amplifiers (fig. 14-6) are used in transmitting except that a 1.85 mc. oscillator replaces the IF stage of the same frequency and a separate preamplifier is used to drive the power amplifier. The initial 1.85 mc. excitation is mixed in the first transmitter mixer stage with the 21.85 to 31.75 mc. injection frequency. The 20.0 to 29.9 mc. output is amplified and then mixed with the 200 to 370 mc. injection frequency, producing the carrier frequency in the 225.0 to 399.9 mc. range. This is fed through the preamplifier into the power amplifier where it is modulated and fed to the antenna.

Injection Oscillator

One of the representative circuits of interest is the A-bank crystal oscillator employed in conjunction with the injection amplifier. This oscillator, shown schematically in figure 14-7, generates a basic frequency of 24.9 to 33.9 mc. in ten steps of 1.0 mc. The tube, V1901, is connected in a crystal-controlled, cathode-coupled circuit called a Butler oscillator. Oscillators of this type are characterized by good stability at relatively high frequencies and are capable of generating many different frequencies without the use of multiplying stages. The circuit permits operation of the crystal at an OVERTONE frequency, which is an odd multiple of the fundamental crystal frequency.

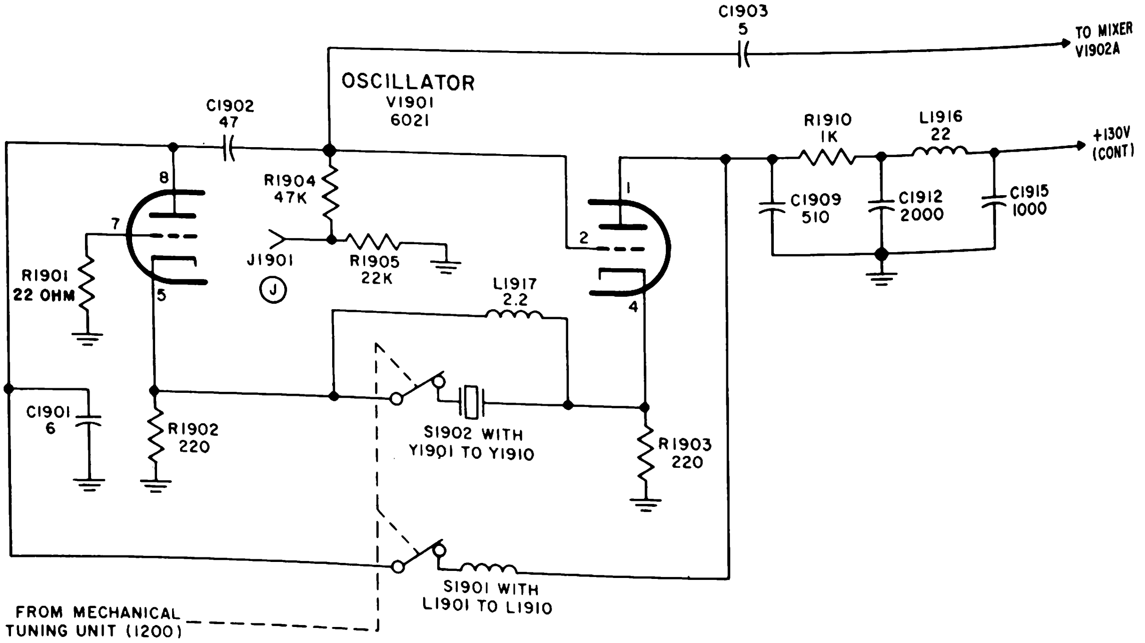


Figure 14-7.—A-bank crystal oscillator.

The crystal (fig. 14-7) is connected between ie cathodes of a twin-triode tube. The proper rystal and associated tuning inductance are elected by the mechanical tuning unit. The ircuit consists of a grounded-grid amplifier nd a cathode follower. The crystal is used as series-resonant wave filter which couples edback from the cathode follower to the input the grounded-grid amplifier. The crystal so determines the frequency of the feedback gnals.

The grounded-grid amplifier supplies the iergy necessary for sustained oscillation in e resonant circuit composed of L1901 and ssociated capacitance. The action of the feed- ick circuit is such that if the cathode of the rounded-grid amplifier swings positive, a posi- ve pulse is returned to it. When the cathode vings negative, a negative pulse is retunred, ereby meeting the necessary conditions of edback for sustained oscillation.

The action of the feedback loop in the Butler cillator (fig. 14-7) takes place in the following quence. Assume that the grounded-grid ampli- r is conducting and that the cathode is swing- more positive. This decreases tube conduc- n and causes the plate voltage to swing in the sitive direction. This voltage change is upled through C1902 to the grid of the cathode lower, where the plate current is increased d the cathode driven to a higher positive poten- l. The positive swing at the cathode is coupled ough the crystal to the cathode of the unded-grid amplifier. This completes the dback circuit and applies energy to the tube such polarity as to sustain oscillation in the ing circuit.

The output of the A-bank oscillator is coupled a mixer stage where it is heterodyned with a nal from the B-bank oscillator (2.15 to 3.05 .) to produce an injection signal of 21.85 to 75 mc.

Microphone Input Circuits and Tone Oscillator

Referring to the ARC-52 block diagram (fig. 3), note the blocks associated with the trans- ter power amplifier. These circuits are the rophone input stage, the modulator, and the sidetone audio stage, all of which are included in the transmitter audio system.

The microphone input amplifier (V701A in fig. 14-8) may be connected for use with either a dynamic microphone or a carbon microphone. Connections are normally made at the time of manufacture, but may be changed as part of a special installation. When using a dynamic microphone, the amplifier operates as a conventional class A circuit, and has sufficient gain to increase the level of the microphone, which has relatively small audio output. A balanced input to ground is provided by the primary of transformer T701. The secondary winding of the transformer is connected in parallel with a variable resistor which controls the input signal level at the grid. The output is coupled through C702 to the grid of a second audio amplifier stage, V701B.

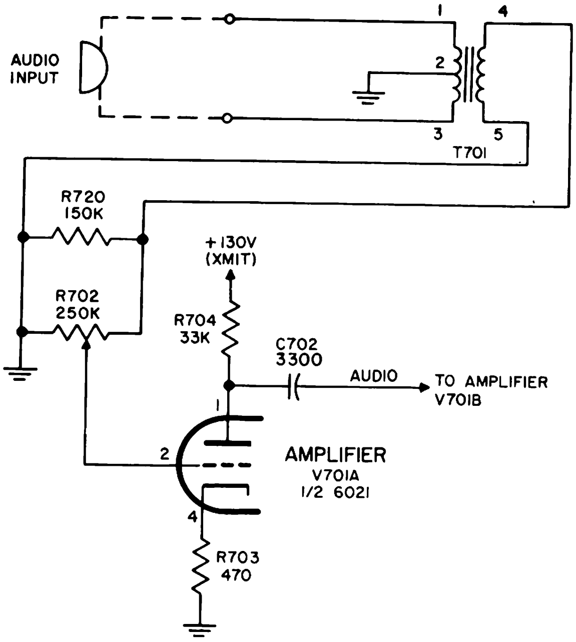


Figure 14-8.—Dynamic microphone input.

When employing a carbon microphone, the circuit arrangement shown in figure 14-9 is used. Tube V701A is then connected as a cathode follower to avoid excessive amplification of the higher level audio provided by the carbon microphone. Since this type of microphone requires a constant current flow, it is connected in series with the 27.5-volt line through current limiting resistor R701, the transformer primary, and

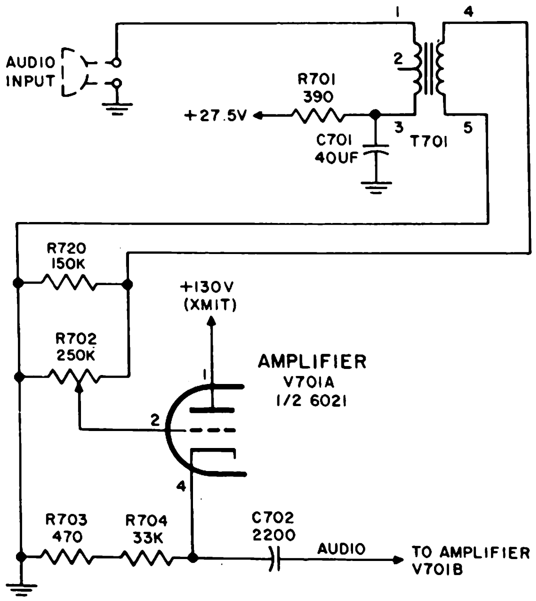


Figure 14-9.—Carbon microphone input.

ground. The audio signal is developed across variable resistor R702. The output of the stage appears across resistors R703 and R704 and is coupled through C702 to the grid of the following audio amplifier.

An alternate audio input signal employed in the ARC-52 transmitter is supplied by the tone oscillator circuit shown in figure 14-10. The tone generator, V705, supplies a 1,000-c.p.s. homing signal when the external tone switch is closed. The action of the switch energizes a tone relay which applies plate voltage to the oscillator and also energizes the transmit-receive relay to place the radio set in the transmit condition.

The tone oscillator is of the phase-shift type with feedback applied to the grid from the plate through three phase-shifting, RC networks. Each RC section introduces a phase displacement of 60 degrees at a frequency of 1,000 c.p.s., so that a total of 180 degrees phase shift occurs, thereby providing the feedback condition necessary for sustained oscillation. The total phase shift at other frequencies differs from 180 degrees and therefore does not sustain oscillation. The oscillator is designed to operate in the range of 920 to 1,120 c.p.s. The tone output is developed across R712 and fed to the grid of the second audio amplifier, V701B.

The Modulator

The modulator supplies the audio energy required to modulate the RF power amplifier of the transmitter. The modulating power is developed by the circuits shown in figure 14-11, the input to which is provided either by the microphone amplifier or by the tone oscillator described in preceeding paragraphs.

The signals applied to the audio power amplifiers (fig. 14-11) are referenced to a negative 15 volts bias which is connected to the center tap of the coupling transformer, T703. A Zener diode (CR701) serves to keep the biasing voltage constant during periods of increased modulation when the grids are drawing current. The power tubes are operated push-pull to obtain higher efficiency and linearity of output. The audio output voltage varies about a positive 450 volts, d.c., and is taken from terminal three of T702 for application to the RF power amplifier.

Capacitor C706 (fig. 14-11) is used as a biasing filter. Resistor R711 is used to develop a voltage for monitoring the modulator cathode current and does not affect the normal operation of the circuit.

RF Power Amplifier

The RF power amplifier, the final stage of the ARC-52 transmitter section, applies modulated UHF signals to the antenna at the power level required. Conventional high-level modulation is employed in this stage.

A simplified schematic of the power amplifier and associated circuits is shown in figure 14-12. The input RF to the final stage is applied from the transmitter preamplifier through two amplifiers, V601 and V602. These are grounded-grid circuits and are operated class C. The audio modulating voltage is applied to the plate and screen grid of the final tube. Modulation is accomplished by superimposing the audio voltage upon the RF output of the stage. The resulting modulated RF energy is coupled through capacitor C615 to the antenna relay subassembly. The coupling capacitor is tuned by the mechanical frequency-selection system so that it presents a constant 50-ohm reactance over the entire frequency range of the equipment. A portion of the modulated output is detected in a sidetone

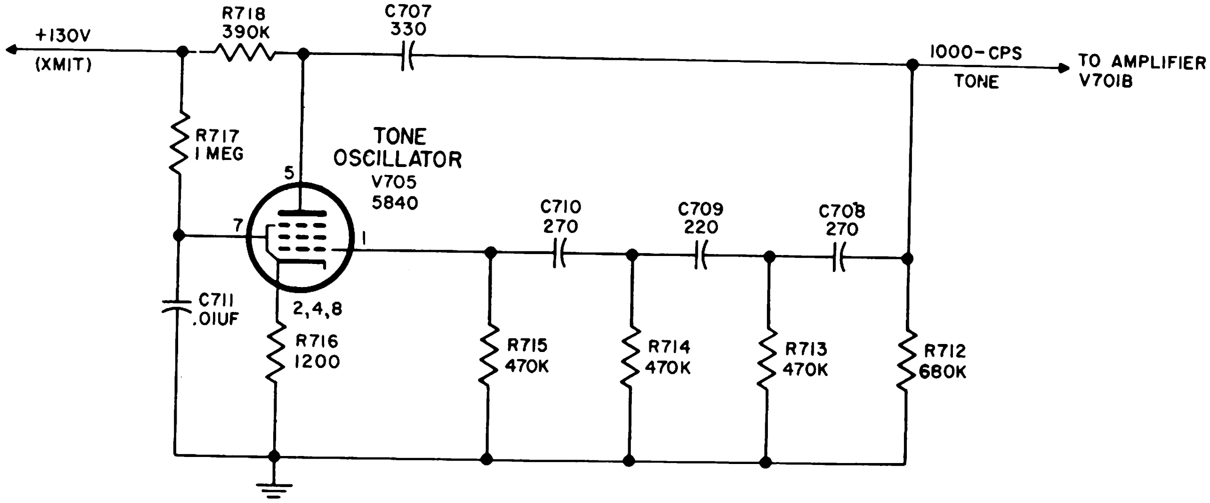


Figure 14-10. –Tone oscillator circuit, ARC-52 transmitter-receiver.

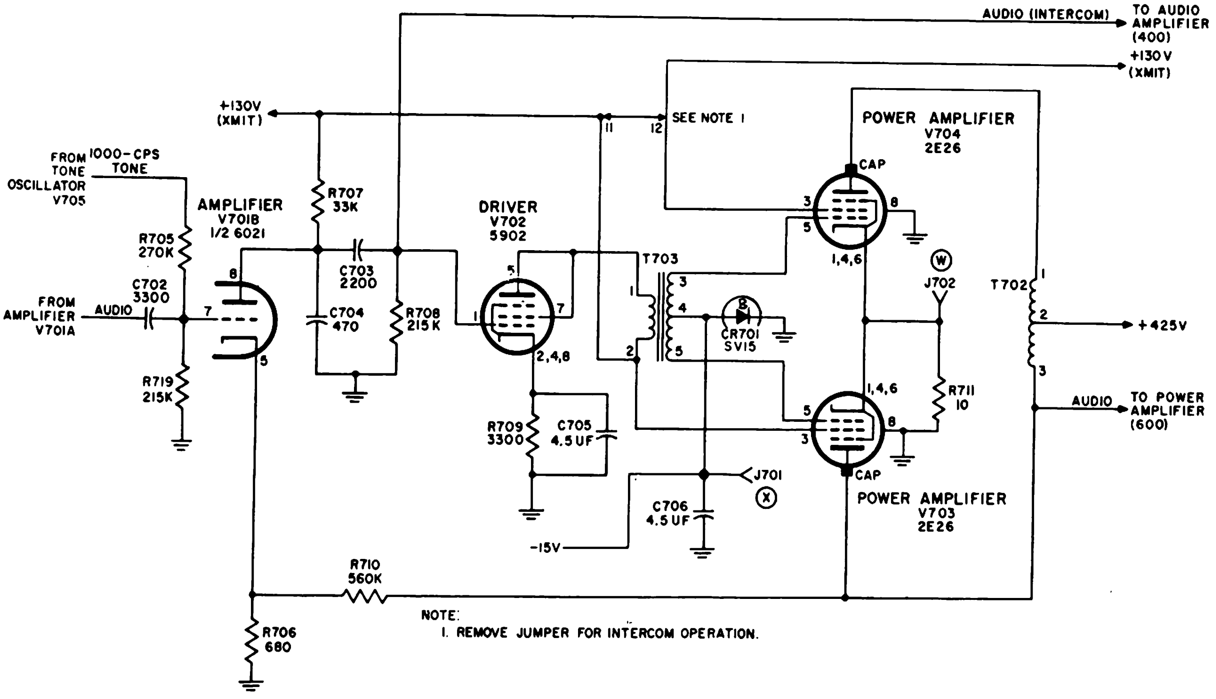


Figure 14-11. –ARC-52 modulator circuits.

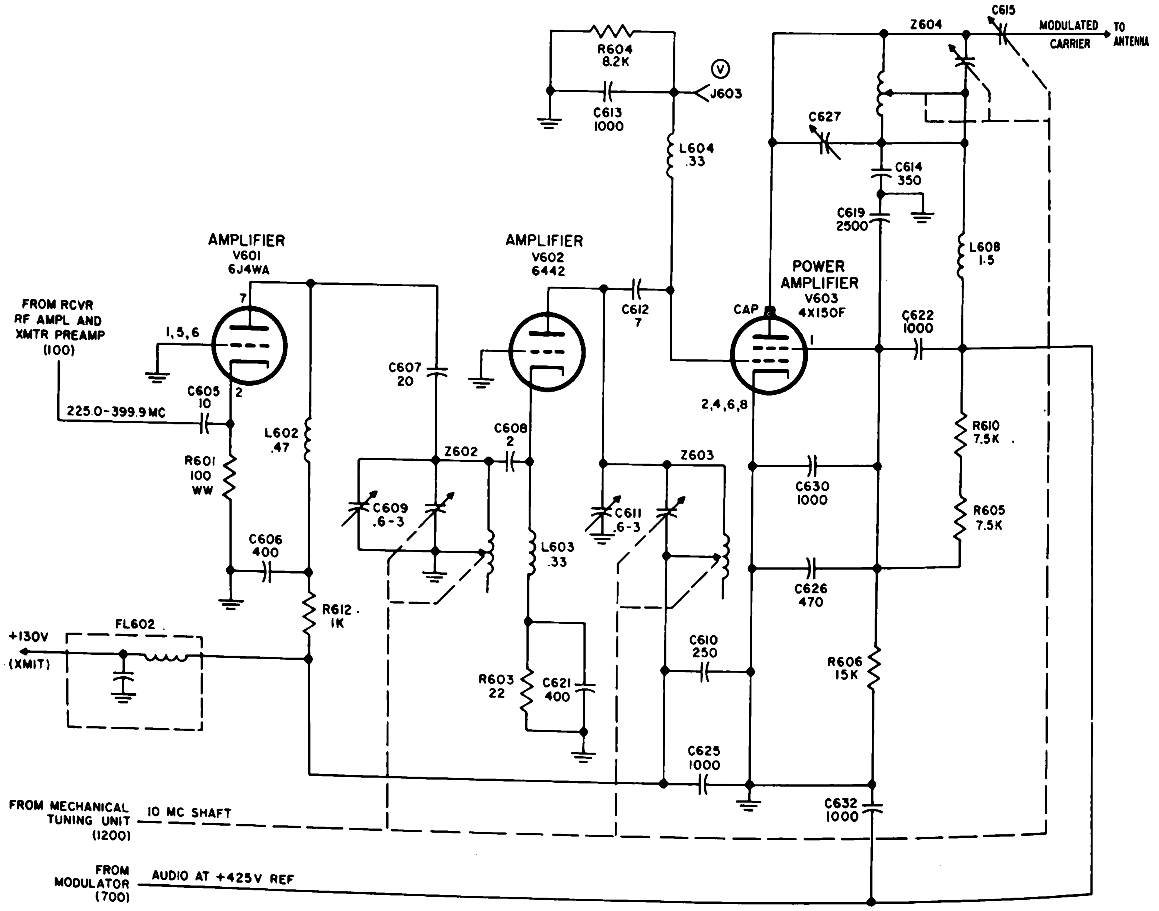


Figure 14-12.—ARC-52 final amplifier.

detector circuit, a part of the antenna relay subassembly. The detector circuit contains a crystal diode rectifier, which produces an audible signal to enable the operator to monitor the transmitted signals.

Test Equipment

The test equipment used in the maintenance of the ARC-52 is the same as that used with the ARC-27. This is general-purpose type equipment with which you should already be familiar, since it has been in use for a number of years. No special test equipment is needed with ARC-52.

DOPPLER NAVIGATION

Doppler navigational radar automatically and continuously computes and displays groundspeed and drift angle of an aircraft in flight, without the aid of ground stations, wind estimates, or true airspeed data. This is done by utilizing auxiliary inputs from an altitude rate sensor and from the aircraft's vertical reference system. The radar section does not sense range and bearing (direction) as ordinary search radar does. Instead, it is SPEED-CONSCIOUS and DRIFT-CONSCIOUS. It employs continuous carrier wave (CW) transmission energy and determines the forward and lateral velocity components of the aircraft by utilizing the principle known as doppler effect.

Review of Doppler Principle

Several approaches have been used to present the theory of the doppler principle. A familiar one is the sound that a stationary observer hears from the whistle of an approaching train, as presented in *AT 3 & 2,* NavPers 10317-A. If you are not familiar with this, or some other discussion, study it before continuing with this discussion. No matter what approach is used, the final conclusion is always the same.

In a doppler navigational radar system, the radar echo received from a moving target has a frequency that is slightly different from the signal generated by the transmitter. In the explanation that follows three aspects of a given radar beam are discussed. These are the generated-signal wave, the incident wave, and the received wave. The timing of the wave is discussed and illustrated to show how phase shift and frequency shift occur.

An examination of one microsecond of the signal radiated from a CW radar transmitter shows that the signal is composed of many cycles of RF energy. In the time of one microsecond a radar that operates at 13.3 kilomegacycles will radiate 13.3 kc. of RF energy, a few cycles of which are shown in figure 14-13(A). Each cycle occupies a definite period of time and has a definite physical wavelength. At the frequency mentioned, each cycle occupies 75 micromicroseconds and has a physical wavelength of 22.5 millimeters. An expanded view of one cycle of RF at 13.3 k.mc. is shown in (B) of the figure. This cycle will later be shown with one cycle of incident signal superimposed on it to demonstrate expansion due to doppler effect.

At this point two approaches to explain the effect of signal expansion are used; one involves the action of a cycle of energy as it leaves the antenna, and the other considers the shape of each cycle to be an arc of wave energy. First, consider a single cycle as it leaves the antenna.

The cycle shown at (B) of figure 14-13 occupies a certain discrete distance in space, and is, in fact, the wavelength of the signal at the frequency shown. When transmitted from a stationary antenna, the leading edge will move out into space 22.5 millimeters, by the time the trailing edge leaves the antenna. The cycle will then occupy its exact wavelength in space. However, if that cycle is emitted from an antenna on a moving aircraft, then the aircraft will move a small distance during the time that the cycle is being transmitted. The trailing edge will, therefore, be a greater distance away from the leading edge than it was when the cycle was transmitted from the stationary antenna. This is expansion.

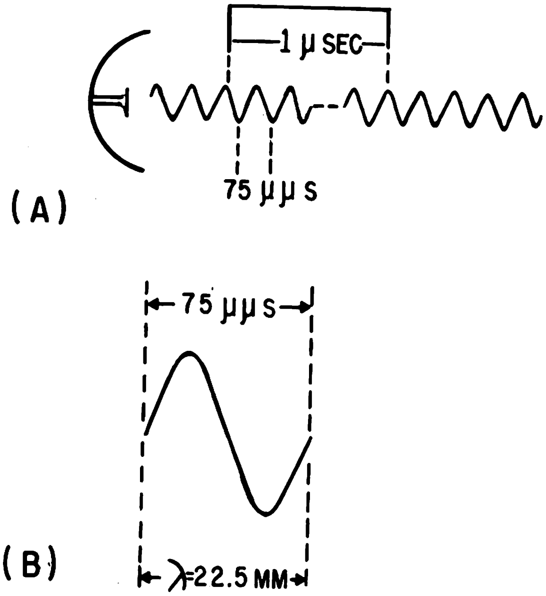


Figure 14-13.—Examination of a pulse.

Figure 14-14 illustrates this effect and shows, by the dotted line, the space that a cycle would have occupied had the antenna been stationary. Inasmuch as the cycle has been expanded, it occupies more distance in space, the wavelength has been increased, and the frequency has been proportionately decreased. The difference in frequency for this first doppler shift can be computed by the formula: doppler shift = $\frac{\text{velocity of aircraft in ft. per second}}{\text{wavelength of generated wave in feet}}$ X sine of the angle of the radar beam from vertical.

When the signal is reflected from the ground and returns to the antenna a similar expansion occurs. A slightly longer time is required for the cycle to reenter the moving antenna than would be required if the antenna were stationary. Thus, a DOUBLE expansion has occurred. This double frequency expansion can be measured by the formula d. s. = $\frac{2\,V}{\lambda}$ x sine ϕ. The change in

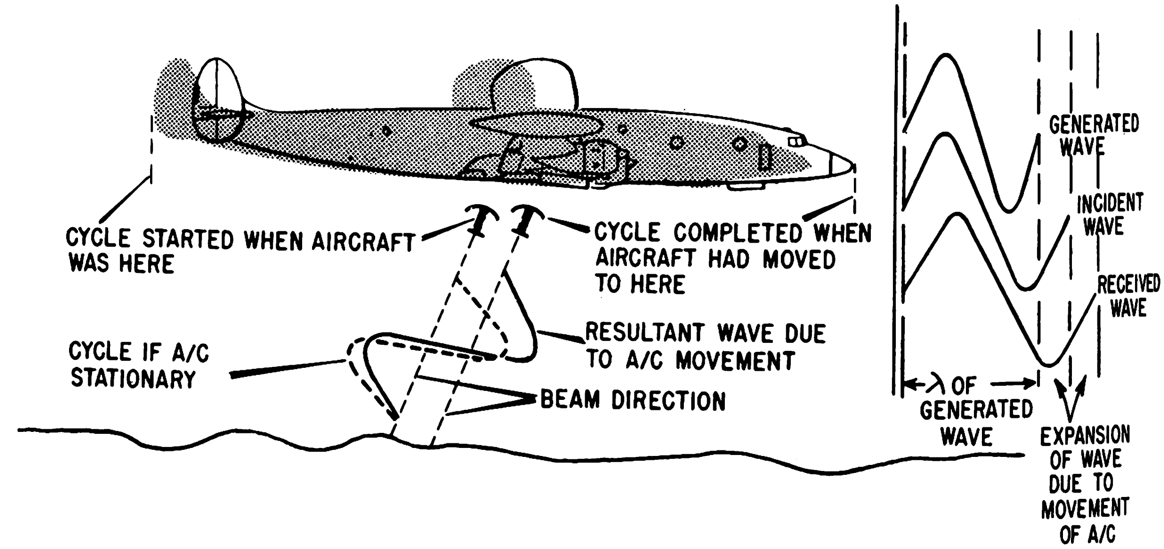

CYCLE STARTED WHEN AIRCRAFT WAS HERE
CYCLE COMPLETED WHEN AIRCRAFT HAD MOVED TO HERE
RESULTANT WAVE DUE TO A/C MOVEMENT
CYCLE IF A/C STATIONARY
BEAM DIRECTION
GENERATED WAVE
INCIDENT WAVE
RECEIVED WAVE
λ OF GENERATED WAVE
EXPANSION OF WAVE DUE TO MOVEMENT OF A/C

Figure 14-14.—One-cycle expansion.

frequency is slight, but measurable, and is a direct indication of the speed of the aircraft.

Compression of the signal will result if the antenna is pointed in the forward direction. The explanation is similar to that of expansion except that the leading and trailing edges of the cycle will be closer together (cycle compressed). The effect will be to shorten the wavelength and increase the frequency.

Another approach to compression and expansion is to consider that a CW signal consists of waves of energy radiated from the antenna. Figure 14-15 illustrates the spacing between the waves of a signal from both stationary and moving antennas. The effect is the same as that previously described. The increased spacing (wavelength) between adjacent waves of energy is a direct indication of frequency change. The received signal frequency, when mixed with the generated signal frequency, produces a difference frequency that is in the audio spectrum. The audiofrequency is a direct indication of the aircraft's speed.

If only one beam were transmitted, speed could be determined in one direction only. With the use of two beams, both the forward and lateral velocity components of the aircraft can be determined. With the use of four beams, as in ASW helicopters, speed and drift can be determined in any direction.

Figure 14-16 shows a block diagram of a typical two-beam system used to determine forward and lateral velocity components of an aircraft.

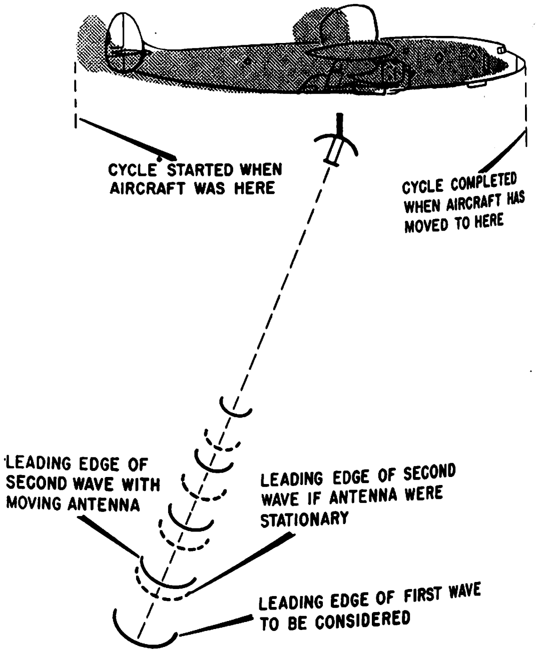

CYCLE STARTED WHEN AIRCRAFT WAS HERE
CYCLE COMPLETED WHEN AIRCRAFT HAS MOVED TO HERE
LEADING EDGE OF SECOND WAVE WITH MOVING ANTENNA
LEADING EDGE OF SECOND WAVE IF ANTENNA WERE STATIONARY
LEADING EDGE OF FIRST WAVE TO BE CONSIDERED

Figure 14-15.—Energy wave spacing.

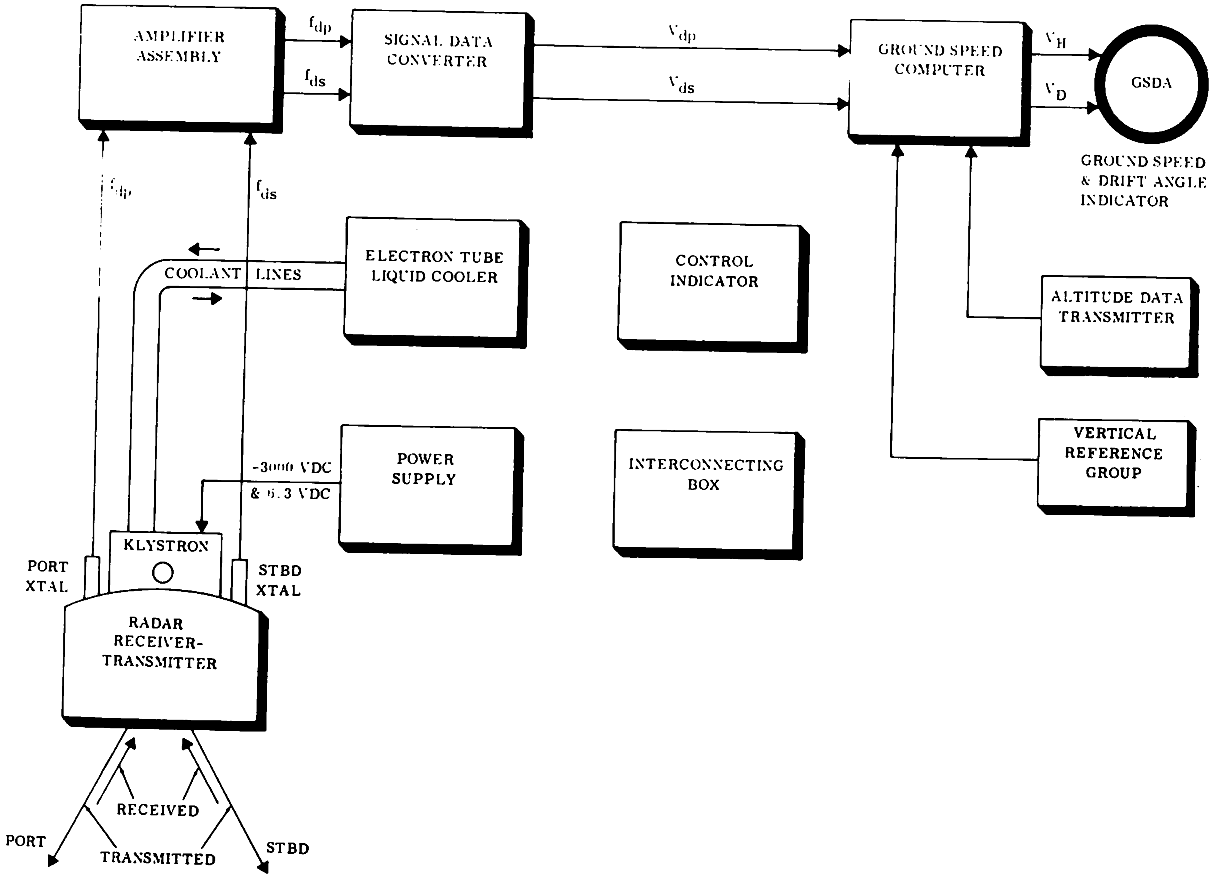


Figure 14-16.—Block diagram of a two-beam doppler radar navigation set.

Operation of Units of Navigation Set

RECEIVER-TRANSMITTER

This unit, shown in figure 14-17, consists of a fiberglass paraboloid which contains a waveguide assembly, two crystal mixer assemblies, and a klystron oscillator assembly. The inner surface of the paraboloid is sprayed with a metallic reflecting material. As well as serving as a container for the various units, the paraboloid also serves as the transmitting and receiving antenna. The paraboloid is divided in the center by a wall called the septum, in which the waveguide is mounted.

Figure 14-18 illustrates the position of the waveguide in the septum, and the transmitting and receiving sections of the antenna. Figure 14-17 shows that the transmitting waveguide originates at the klystron and is a T-shaped section terminating in two radiating horns (only one transmitting horn is visible in the top drawing). Two receiving waveguide sections are attached to the transmitting section. They have crystal-mixer cavities mounted at the upper ends, receiving horns at the lower ends and coupling slots provided between each receiving and transmitting section. The klystron, mounted at the center of the waveguide, receives d-c filament and cathode power from the high voltage power supply, and liquid coolant from the electron tube liquid cooler. The klystron is a dual cavity resonator. The CW energy from the klystron cavity is coupled to the waveguide through an impedance matching aperture located in the end of the waveguide, and through a coupling choke built into the waveguide flange. The energy is coupled down through the waveguide to the T-section where a power divider sends half of the energy to each transmitting horn. The power divider is a small probe located across the waveguide at the center of the T-section.

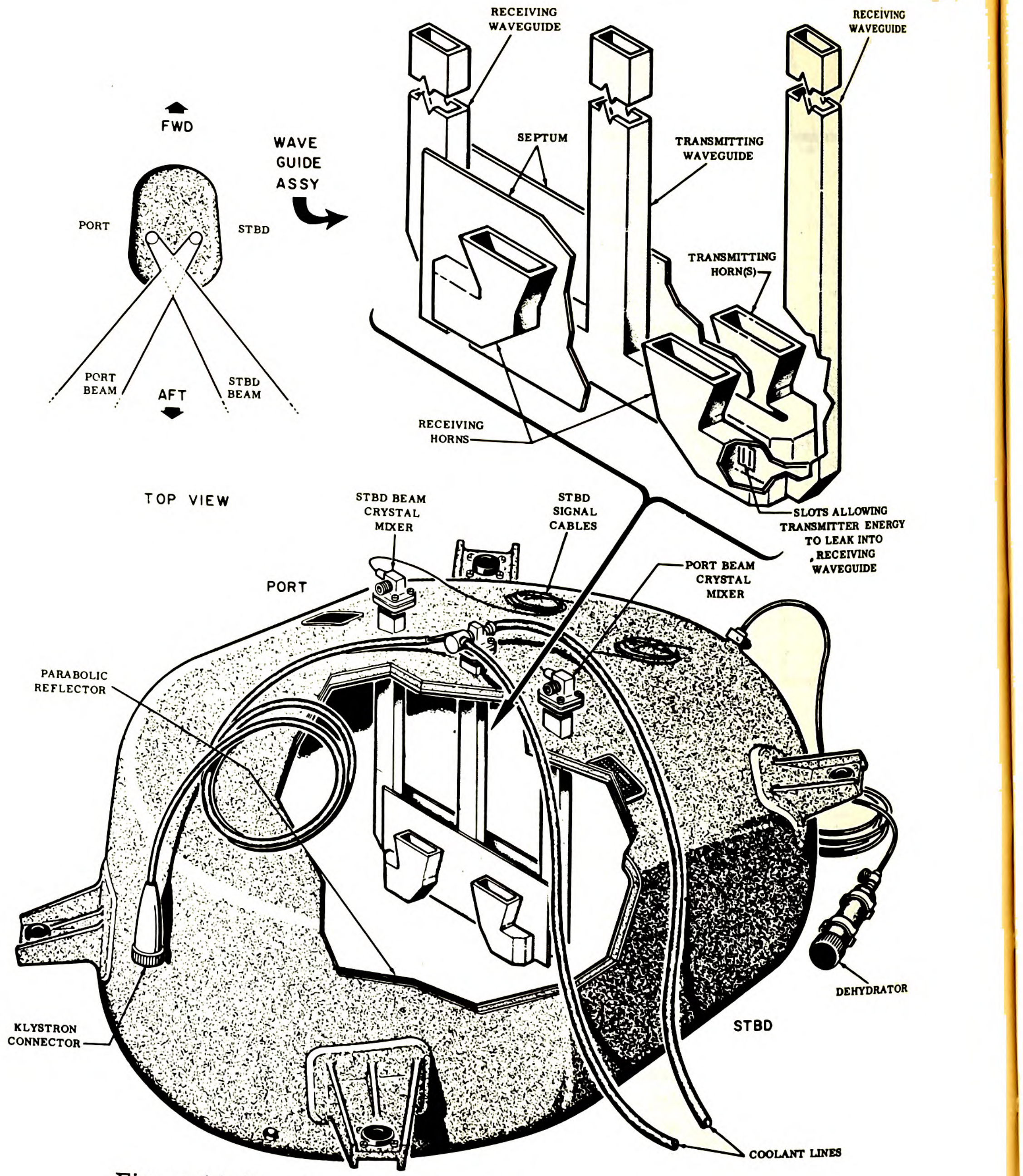


Figure 14-17.—Receiver-transmitter, mechanical assembly.

The reflecting surface of the antenna dish concentrates the energy into two narrow beams on opposite sides of the aircraft. These beams are directed outboard and downward, to the rear of the aircraft, as shown in figure 14-19. The beams are directed outboard from the aircraft vertical through an angle of 11 degrees, and thence aft from this position through an angle of 22 degrees. Since the beam width has a certain physical volume, it covers a definite area when the radiation energy strikes the ground. As a consequence, the angle of incidence and the direction of the energy reflected from the ground vary as shown in figure 14-20(A). More specifically, the result is that the energy striking the ground at the steepest angle relative to the longitudinal axis of the aircraft returns at the highest frequency and produces the lowest doppler

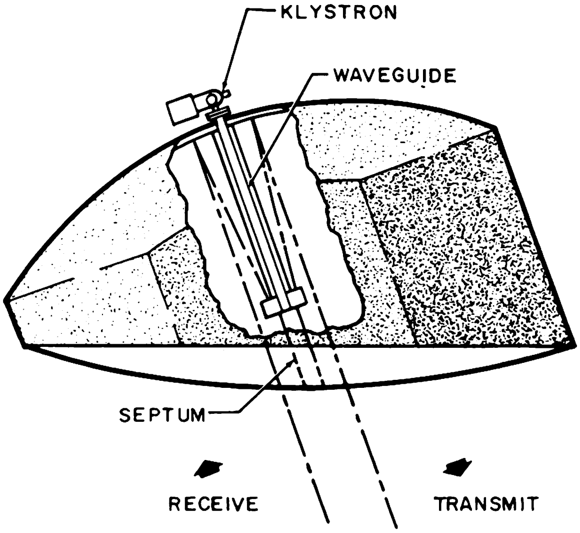


Figure 14-18.—Location of waveguide in septum.

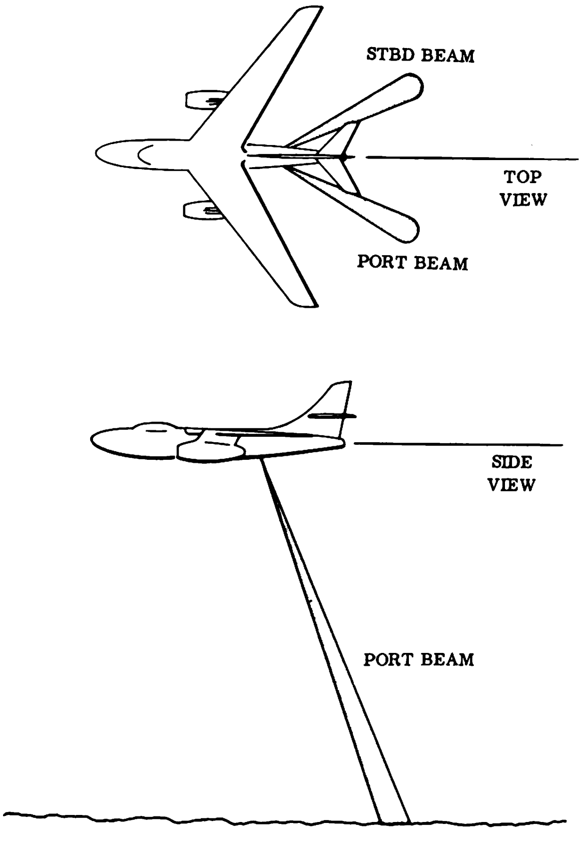


Figure 14-19.—Beam orientation in radar navigation

frequency; and the energy striking the ground at the flattest angle returns at the lowest frequency, producing the highest doppler frequency. There will be a general frequency band or spectrum between these two doppler frequency extremes, and the energy transmitted at the center and received from the center of the radiation lobe will be at the greatest power and at approximately the center frequency of this band.

Figure 14-20(B) shows a typical doppler frequency spectrum with the approximate center frequency at the greatest power level. The reflected energy is picked up by the receiving half of the antenna and focused into the receiving horns. This energy is directed through the waveguides to the receiving crystal mixer cavities. The impedance of the waveguide is matched to the crystal mixer by a matching aperture located at the coupling flange. The flange also contains a coupling choke to prevent loss of energy at this junction. A sampling of the transmitter's energy leaks into the receiving waveguides through two narrow coupling slots between the two sections of the transmitting and receiving waveguides. (See fig. 14-17.) These coupling apertures attenuate the transmitted energy so that only a small portion of its power is supplied to the receiving waveguide.

The crystal is placed across the cavity at a voltage point as shown in figure 14-21 and functions as a pickup probe and as a mixer. Both the transmitted and received signals appear across the crystal, and since it is a nonlinear device, mixing action results. The sum and difference, and each of the two input frequencies, appear across the output of the crystal, but the sum and the two input frequencies are shunted to ground by the capacities formed by the vinyl insulating washers supporting the crystal at its output end. The output from each crystal mixer is a doppler frequency proportional to the velocity along its respective beam (port or starboard). (See fig. 14-22(A).) If the aircraft is drifting in the port direction (fig. 14-22(B)) the doppler frequency output of the port crystal mixer will be lower than the output of the starboard crystal mixer. If the aircraft drifts toward starboard, the output of the starboard mixer will be lower. The difference or doppler frequency is within the audio spectrum. It is coupled from the crystal to the dual channel amplifier assembly.

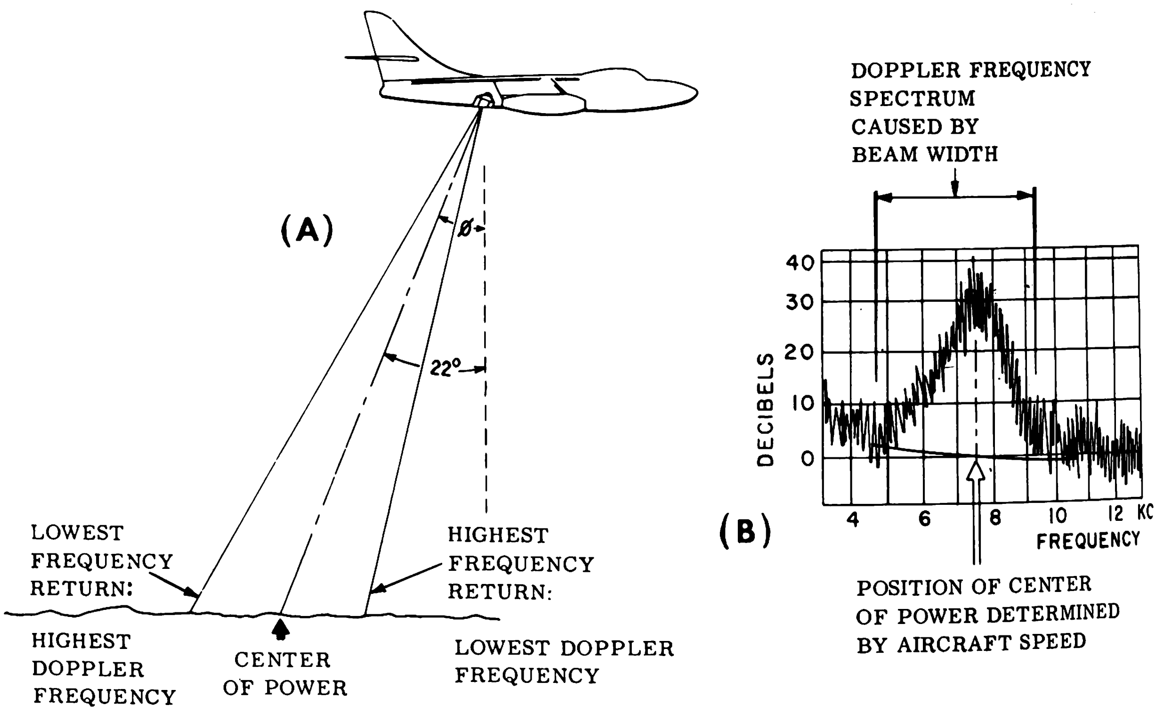

(A)
Ø
22°
LOWEST FREQUENCY RETURN:
HIGHEST DOPPLER FREQUENCY
CENTER OF POWER
HIGHEST FREQUENCY RETURN:
LOWEST DOPPLER FREQUENCY
DOPPLER FREQUENCY SPECTRUM CAUSED BY BEAM WIDTH
40
30
20
10
0
DECIBELS
4
6
8
10
12 KC
FREQUENCY
(B)
POSITION OF CENTER OF POWER DETERMINED BY AIRCRAFT SPEED

Figure 14-20.—Frequency spectrum of reflected energy.

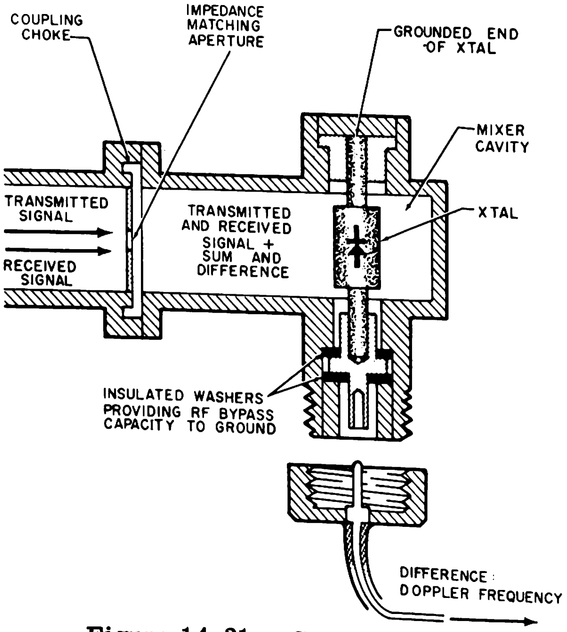

COUPLING CHOKE
IMPEDANCE MATCHING APERTURE
GROUNDED END OF XTAL
MIXER CAVITY
XTAL
TRANSMITTED SIGNAL
RECEIVED SIGNAL
TRANSMITTED AND RECEIVED SIGNAL + SUM AND DIFFERENCE
INSULATED WASHERS PROVIDING RF BYPASS CAPACITY TO GROUND
DIFFERENCE DOPPLER FREQUENCY

Figure 14-21.—Crystal mixer assembly

AMPLIFIER ASSEMBLY

This unit contains two separate fully transistorized preamplifier channels. One is for the port beam doppler signal, and the other is for the starboard beam doppler signal. These signals come from the crystal detectors of the receiver-transmitter. The assembly also incorporates a transistor oscillator circuit which generates a simulation doppler signal for test purposes.

The port and starboard doppler signals are amplified under AGC control and thence delivered to the signal data converter.

SIGNAL DATA CONVERTER

This unit contains circuitry which searches, acquires, and tracks the center frequencies of the doppler frequency spectra supplied from the port and starboard signal channels of the amplifier assembly. As soon as satisfactory acquisition is made of these center doppler frequencies (while the system unit is in the search mode) the circuitry automatically switches to the track mode and generates two analog voltages in the form of 400 c.p.s. tachometer output signals. One output potential is proportional to the center doppler frequency that is present in the port signal channel, and the other is proportional to the center doppler frequency of the starboard

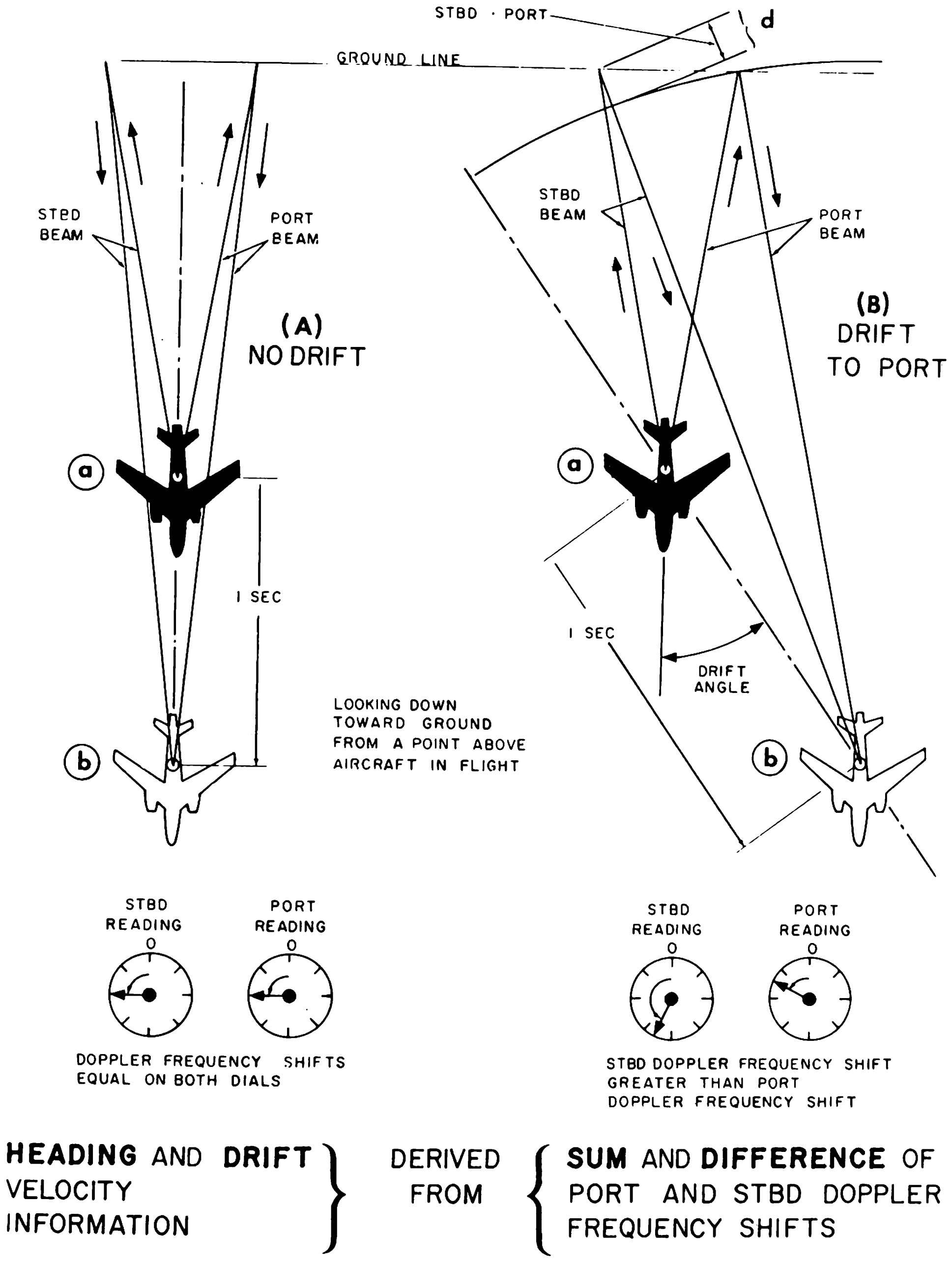

STBD · PORT
d
GROUND LINE
STBD BEAM
PORT BEAM
(A) NO DRIFT
a
I SEC
b
LOOKING DOWN TOWARD GROUND FROM A POINT ABOVE AIRCRAFT IN FLIGHT
STBD BEAM
PORT BEAM
(B) DRIFT TO PORT
a
I SEC
DRIFT ANGLE
b
STBD READING
PORT READING
0
0
DOPPLER FREQUENCY SHIFTS EQUAL ON BOTH DIALS
STBD READING
PORT READING
0
0
STBD DOPPLER FREQUENCY SHIFT GREATER THAN PORT DOPPLER FREQUENCY SHIFT
HEADING AND DRIFT VELOCITY INFORMATION
DERIVED FROM
SUM AND DIFFERENCE OF PORT AND STBD DOPPLER FREQUENCY SHIFTS

Figure 14-22.—Doppler frequency shift—effect of shift on dual beams.

channel. These output signals represent the velocity components of aircraft motion measured in the direction of the two radiation beams.

Insufficient strength or loss of a doppler signal in either channel causes the signal data converter to send out a trigger signal which puts the computation section of the system on memory, while track operation is still maintained. If after a two-second delay the lost signal has not been recaptured, search operation is resumed and the memory status for the computation process sustained. (When the system is on memory, the computation values are frozen to those last obtained before signal loss.) If the signal is recovered before the two-second time delay has elapsed, the signal data converter continues to remain in the track mode and terminates the memory status at the end of the delay period by removing the memory (trigger) signal, thus allowing the computation to continue from the held-over values. If normal signal strength is restored in both channels after resumption of search operation, the signal data converter again goes through acquisition and returns to the track mode two seconds after signal restoration, and allows the computation process to be resumed (memory signal off). Special circuit design prevents the signal data converter from locking onto noise signals and facilitates operation over a great range of doppler signals. The two analog voltages, representing port and starboard beam velocities, are then applied to the groundspeed computer.

GROUNDSPEED COMPUTER

This unit is an electromechanical analog computer. Its function is to convert the output potentials from the signal data converter (which are proportional to the aircraft's velocity components in the direction of the radiation beams) into potentials representative of the ground-observed heading and drift velocity components of the aircraft. From these ground-observed velocity components, the groundspeed of the aircraft can be readily determined. The signal transformation is carried out in two steps. One step involves conversion of the port and starboard signal voltages into velocity signals in the three coordinate axes of the aircraft. The other step involves rotation of these three velocity components into the three axes of a ground reference coordinate system. For the latter step, two electromechanical resolvers are utilized in conjunction with auxiliary signal inputs (roll angle, pitch angle, altitude rate) from airborne reference sources. The two resultant output signals from the groundspeed computer (heading velocity component and drift velocity component) are made available in the form of 400 c.p.s. signal potentials which are fed into the groundspeed and drift indicator.

GROUNDSPEED AND DRIFT ANGLE INDICATOR

This unit extracts groundspeed and drift angle information from the output data of the groundspeed computer and visually displays this information on a circular, dual-scale indicator dial on the face of the cylindrical unit housing. The upper peripheral scale on this dial reads groundspeed from 80 to 800 knots if indicator ID-733/APN-122 is used, or 80 to 400 knots if indicator ID-757/APN-122 is used. The bottom scale reads to 45 degrees drift angle to the right and left from zero. The same information is also made available in the form of synchro output signals for utilization in ground position computers and other navigational equipment.

POWER SUPPLY

The power supply provides the high operating potential (negative 3,000 volts d.c.) and the filament power (6.3 volts d.c., regulated) for the klystron. To attain the precision output voltage and load regulation required, the power supply uses a magnetic amplifier for regulating the three-phase a-c input, and a standard high voltage regulation circuit in the output. An interlock circuit protects the power supply and klystron by opening the transmitter high voltage circuit under the following conditions:

a. Filament power failure to the transmitter.
b. Excessive transmitter beam current.
c. Overheating of the transmitter and/or liquid coolant.
d. Coolant pressure failure.

The interlock system also serves as a safety device for maintenance personnel by shutting down the high voltage supply whenever cable connections between units are broken. The power supply is charged with dry nitrogen gas to standard atmospheric pressure through a valve on the front panel.

ELECTRON TUBE LIQUID COOLER

This system is used to cool the klystron. It contains all the parts of a cooling system, such as a reservoir, a heat exchanger, a pressure relief valve, a filter and the associated plumbing. A Monsanto OS-45 fluid is used as the coolant. A pressure-sensitive switch protects the transmitter from low coolant pressure by turning off the transmitter's high voltage when the operating pressure falls below approximately 8 p.s.i. Thermostatic switches automatically turn off the transmitter's high voltage when the pump or fan motor overheats or the coolant temperature exceeds 100°C. (212°F.).

ALTITUDE DATA TRANSMITTER

This unit measures pressure changes with changes in altitude and develops synchro output signals which are proportional to these changes. It contains two evacuated diaphragms which are mounted inside a sealed housing. The inside of the housing is held under atmospheric pressure by a tube connection to the static pressure line of the aircraft. Changes in air pressure inside the housing (resulting from altitude changes) act to contract or expand the diaphragms. The diaphragms are linked to a synchro transmitter rotor through altimeter mechanisms. These are designed to produce 360 degrees rotation per 1,000 feet of altitude change in either direction. Rotor rotation thus provides a synchro transmitter signal proportional to, and in the sense of, altitude change. This signal is converted into a rate signal in the groundspeed converter, and thus provides rate of ascent and descent of the aircraft to the groundspeed computer.

RADAR, AN/APS-82

Radar set AN/APS-82 functions as part of an integrated AEW (Aircraft Early Warning) system. It is a lightweight, airborne, early-warning and control system used to detect targets, accurately determine target azimuth, range, and height, and direct an interceptor on a target collision-intercept or target offset-intercept course. The major components are shown in figures 14-23 and 14-24. It is possible to operate the set in six separate modes, each of which provides a separate function. These modes are Search, Height-Finding, Intercept, Offset-Intercept, Wind Compute, and Relay Link Transmission. Each will be described.

SEARCH MODE

In the search mode, radar data is displayed on a conventional PPI. Two separately controlled electronic cursors and range strobes are used to display and determine target azimuth and range with respect to the AEW aircraft or to any other position. The entire display may be offset as required for better presentation of any section of sweep. Both range and bearing of the target along each cursor are displayed on direct-reading counters on the azimuth-range indicator (IP-414/APA-125) panel. Two separate azimuth-range indicators are provided to allow two operators to share the duty load.

HEIGHT-FINDING MODE

In the target height-finding mode of operation, the system accurately displays the height of any airborne target above sea level. (Since the system is designed for AEW operation over water, terrain altitude is not significant). An accurately controlled antenna tilt and stabilization system is used to determine target vertical position with respect to the antenna boresight axis, which is presented on the height indicator (IP-435/APS-82) as a "Pisa" (leaning rectangular pulse) display. A manual antenna elevation control on the height indicator panel allows the operator to change the antenna tilt angle as required to move the Pisa display to the horizontal position. When the Pisa display is horizontal, the antenna has stabilized at the correct tilt angle, and a direct reading, two-digit counter on the height indicator panel displays target altitude above sea level in thousands of feet. Two height indicators are provided with the radar set which allow the operators to share the watch. However, only one indicator may be used at a time.

INTERCEPT MODE

In the intercept mode of operation, the AN/APS-82 semiautomatically computes the time-to-go along target and interceptor cursors until an intercept occurs. The cursors used in the search mode to indicate target bearing and range with respect to the AEW aircraft are also used to represent the target and interceptor courses so that an intercept point may be chosen. An advance (time) strobe, associated with each cursor, is used to determine whether or not the selected intercept course will result in simultaneous arrival of target and interceptor at the selected point. When the advance strobes coincide at the selected intersection of the target and interceptor cursors, the correct time-to-go is displayed in minutes and seconds on a direct-reading counter located on the computer control (C-2305/APS-82).

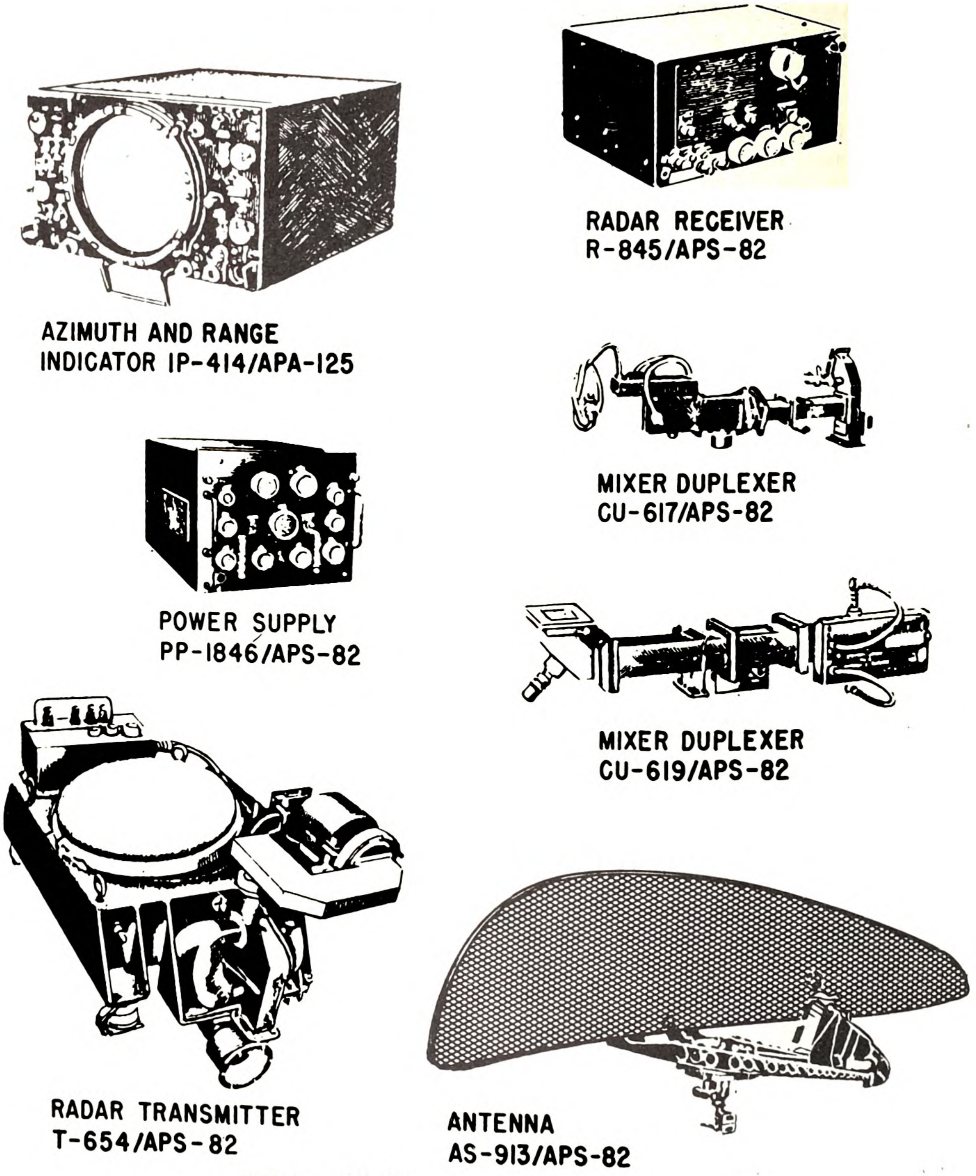


Figure 14-23.—Major units of APS-82.

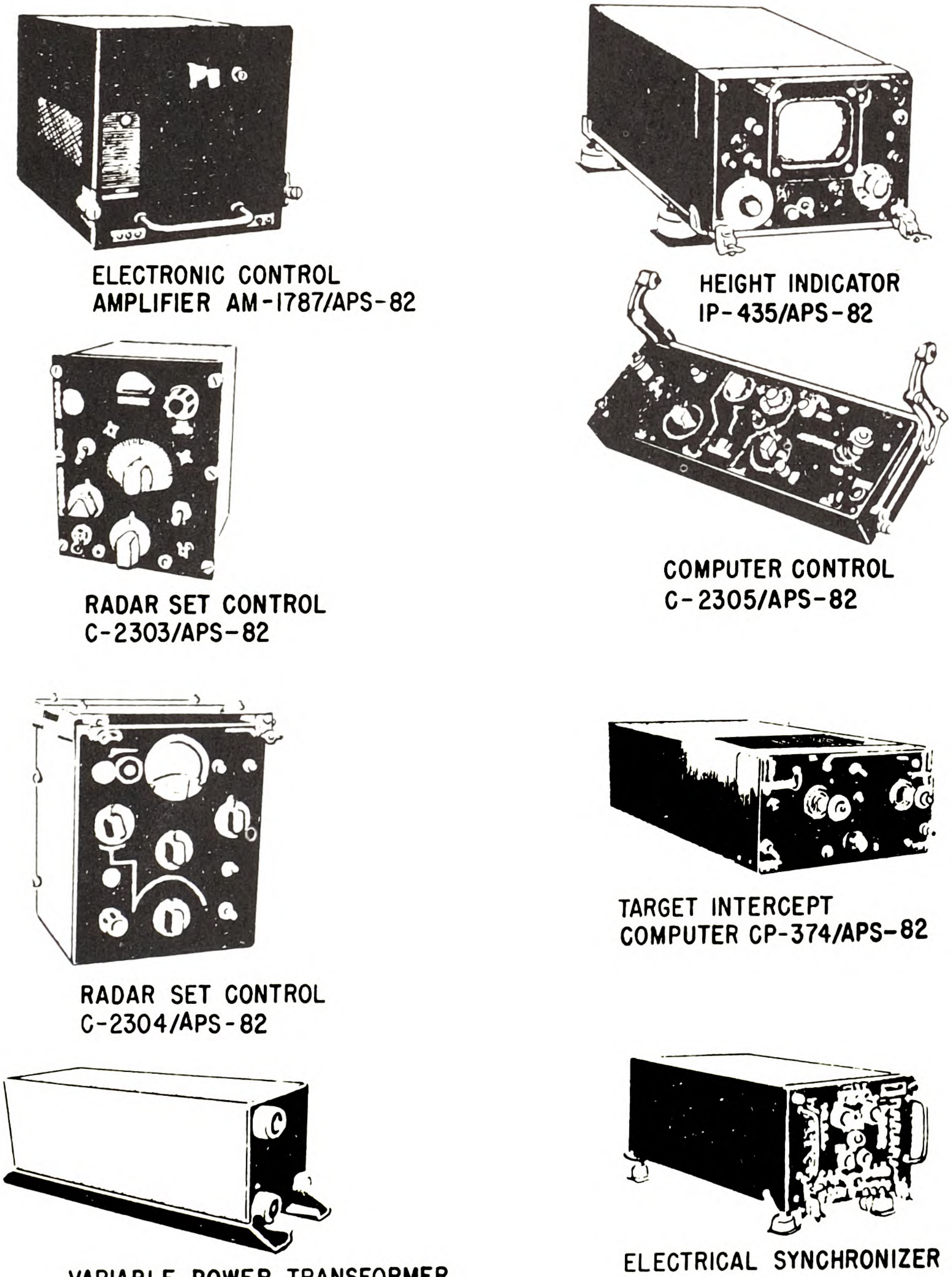
The semiautomatic nature of the intercept computation allows the AEW operator to make rapid corrections by observing the PPI display on the azimuth-range indicator and by operating the pushbutton reset switches located near the cursor-control joysticks on the computer control.

OFFSET-INTERCEPT MODE

Offset-intercept operation is a refinement of intercept operation, in that the time-to-go is computed with respect to the point at which the interceptor must make a coordinated turn into a broadside intercept course. In this mode of operation, it is necessary that the AEW operator know the type of interceptor as well as its speed, so that the most effective broadside intercept course may be plotted. Offset distance and angle settings are made in accordance with the type of interceptor being directed. All other intercept computations and operator functions remain unchanged.

WIND COMPUTE MODE

One of the two operator positions of the AN/APS-82 is equipped with a wind computer, which



ELECTRONIC CONTROL AMPLIFIER AM-1787/APS-82

HEIGHT INDICATOR IP-435/APS-82

RADAR SET CONTROL C-2303/APS-82

COMPUTER CONTROL C-2305/APS-82

RADAR SET CONTROL C-2304/APS-82

TARGET INTERCEPT COMPUTER CP-374/APS-82

VARIABLE POWER TRANSFORMER TF-258/APS-82

ELECTRICAL SYNCHRONIZER SN-199/A

Figure 14-24.—Major units of APS-82.

is not part of the radar set. The operator working this position may use the wind computer in conjunction with Target Intercept Computer CP-374/APS-82 to determine speed and direction of wind at the AEW aircraft. This operation is similar to intercept computing, except that a fixed target is used.

RELAY-LINK TRANSMISSION

In this mode of operation, radar and IFF data are coded and applied, together with synchronizing signals, to a Radar Relay Transmitter T-271/ART-28. Information is transmitted to a surface-based control center to aid in coordinating AEW activities among the fleet's aircraft. All that is required of the operator to cause this information to be transmitted is to turn on the ART-28 by use of an off-on switch.

Circuitry and Theory

The functional units of the radar set are shown in simplified block diagram form in figure 14-25. The system operates similarly to conventional S-band search radars, with the exception of the height-finding capability, which uses the monopulse technique.

MONOPULSE TECHNIQUE

This technique divides the echo pulse into two pulses—one designated SUM and one designated DIFFERENCE. These return signals are received through a sum channel and a difference

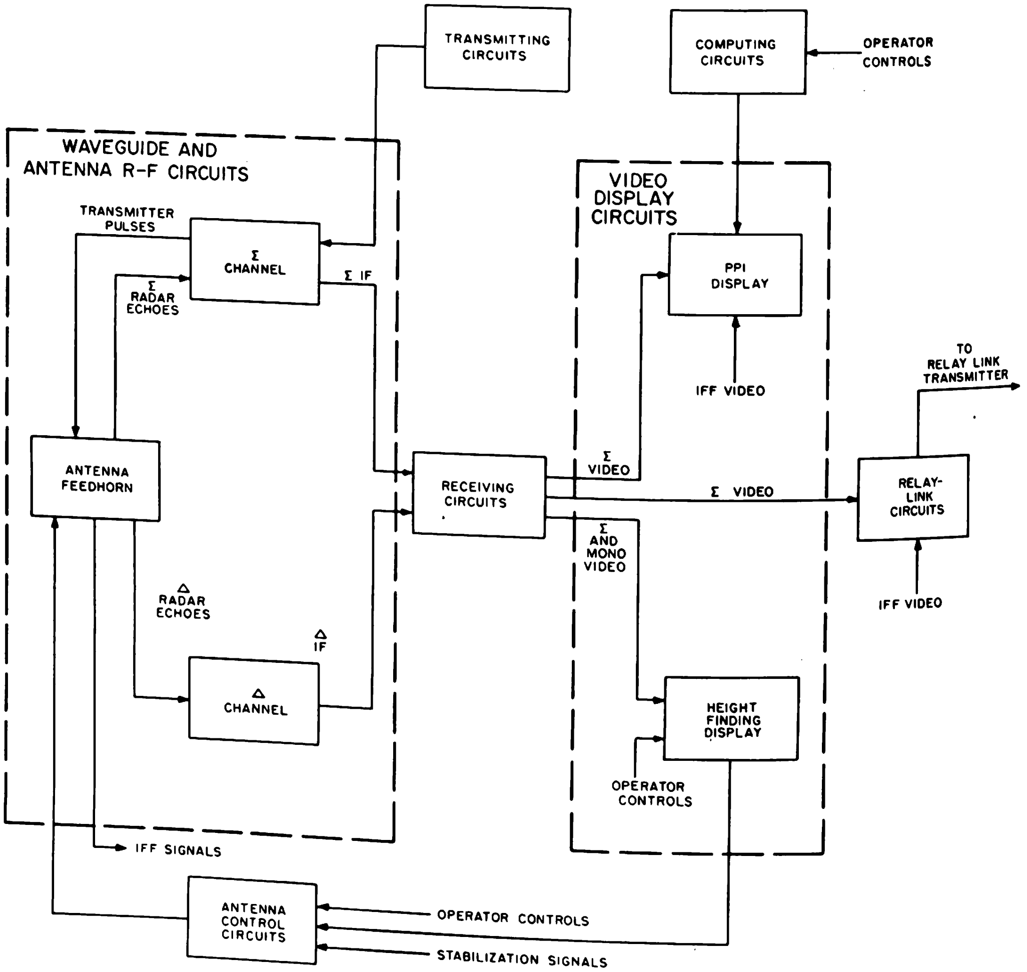


Figure 14-25.—Simplified block diagram, radar set APS-82.

channel and compared in the receiver system. The resultant may be a single positive or negative pulse, the amplitude of which is proportional to the difference in target height from that of the radar's vertical beam axis. The polarity of the pulse indicates whether the target is above or below the radar's vertical beam axis. Since only a single lobe of energy is transmitted, the antenna feedhorn is constructed in a modified MAGIC-T configuration that will respond to variations in the vertical pattern of the received signal.

The feedhorn comprises two functional antenna sections; one for the sum channel and one for the difference channel. Note, however, that only the sum channel antenna section is used for transmission. The primary receiving element is the SUM CHANNEL waveguide-and-feedhorn configuration. This horn is an impedance matching device used to propagate the transmitted pulses into the atmosphere and to shape the pattern radiated against the reflector. Echoes reflected from targets enter the end of the horn as a single receiving pattern and are propagated through the waveguide for sum video signals.

The secondary receiving channel (difference channel antenna section) consists of the MAGIC-T connection, which is incorporated into the sum channel feedhorn configuration. (See fig. 14-26.) The magic-T slot effectively divides the receiving feedhorn into two parts, thus providing two separate receiving patterns.

As shown in figure 14-26(A), a magic-T consists of four energy paths with a common junction. Transmitted energy in path 3 is propagated in equal amounts in paths 1 and 2, none is propagated in path 4 since no field-strength difference exists across its face (which is at right angles to the transverse-electric mode). Target returns appearing at paths 1 and 2 in equal field strengths are therefore propagated in path 3 but not in path 4 since, again, no field strength difference exists across its face. However, if the received signals appearing at paths 1 and 2 are not of equal field strength, a potential difference exists across the face of path 4 and energy is propagated into this waveguide in an amount proportional to the difference in field strengths between paths 1 and 2. Since the potential difference can be of either polarity, depending upon whether path 1 or 2 is supplied the greater input signal, the energy propagated in path 4 will be either in phase or out of phase with the combined (sum) energy which is always propagated in path 3. The feedhorn-and-slot arrangement used in the radar set (fig. 14-26 (B)) is similar to the magic-T (fig. 14-26(A)). The sum channel is equivalent to path 3 of the magic-T. The difference channel waveguide is equivalent to path 4 of the magic-T. Received energy enters the horn simultaneously via paths 1 and 2. There is no physical surface separating paths 1 and 2, but the location of the magic-T slot along the boresight of the feedhorn effectively separates the horn into two identical halves. Each half of the horn is a separate waveguide energy path, or receiving antenna, having its own sensitivity pattern as shown in figure 14-27. The upper lobe of the receiving-sensitivity pattern has arbitrarily been designated as the plus (+) lobe and the lower lobe as the minus (-) lobe. It must be understood that polarity and phase are not involved since no energy is radiated.

When the target is located along the boresight of the antenna, the plus (+) and the minus (-) lobes overlap. Equal sensitivities exist for both energy paths 1 and 2 and no difference signals are propagated. When a target is located above the boresight axis of the feedhorn the upper half of the antenna is more sensitive to radar echoes than the lower half. Thus, a target located in the (+) lobe is detected more strongly by the upper half of the antenna than by the lower half, resulting in a field-strength difference between paths 1 and 2 of the feedhorn magic-T. A potential difference therefore exists across the magic-T slot (path 4), and a small amount of energy is propagated in the difference waveguide. The amount of energy propagated in the difference waveguide is directly related to the difference in field strength between the echoes received in the two halves of the feedhorn, paths 1 and 2.

When a target is located below the boresight axis of the feedhorn, the lower half of the antenna is more sensitive to radar echoes than the upper half. Thus, a target located in the minus (-) lobe is detected more strongly by the lower half of the antenna than by the upper half.

The phase relation of the difference and sum signals is determined by the physical position of the magic-T slot with respect to the opening into the sum-channel waveguide. The AN/APS-82 antenna configuration is chosen so that a difference signal, which is caused by greater energy in path 1 than in path 2, is in phase with the sum channel reception, while the reverse energy condition results in the opposite phase. Note

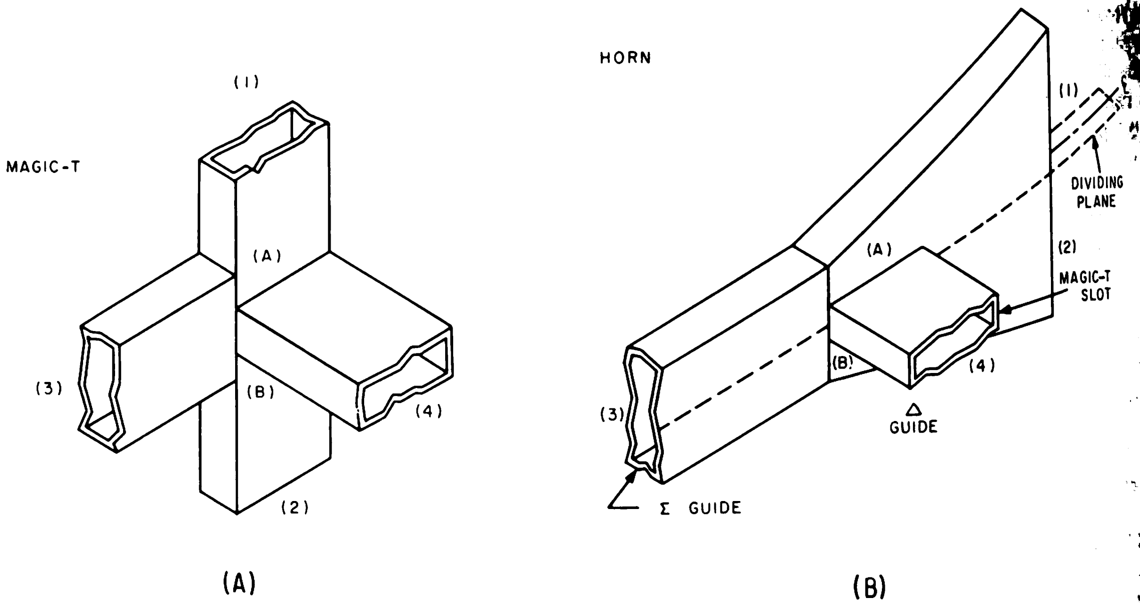


Figure 14-26.—Magic-T configuration, simplified diagram.

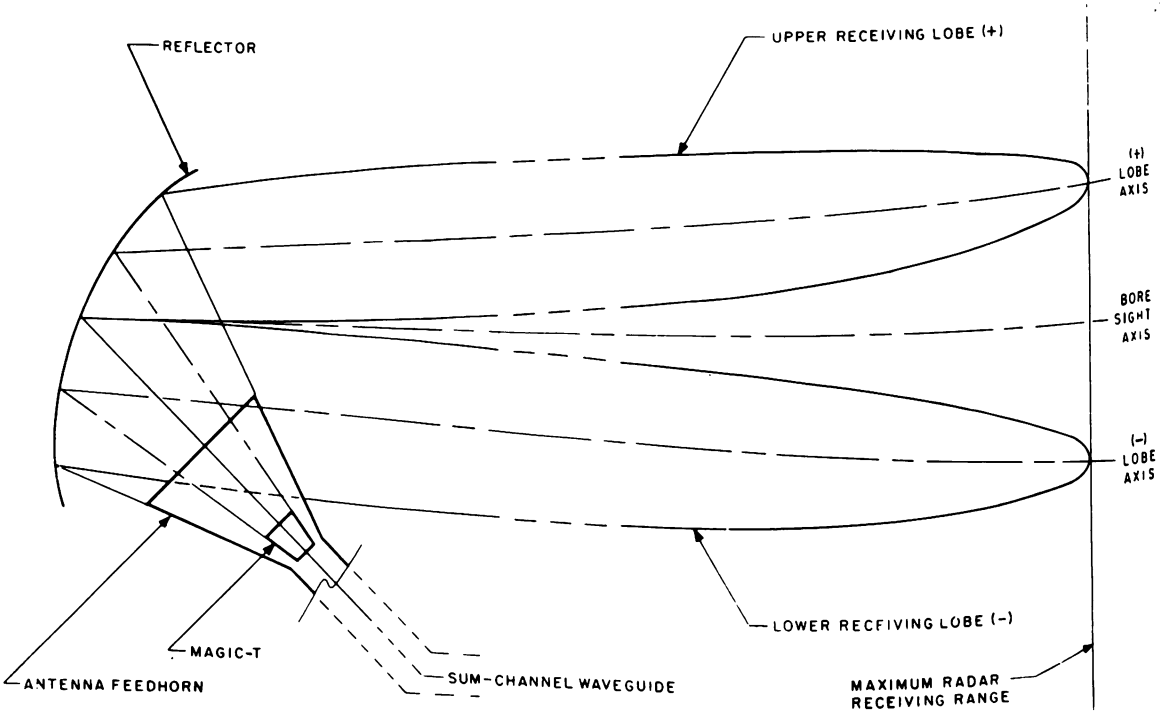


Figure 14-27 —Receiving sensitivity pattern.

iat only a small portion of the total received nergy is coupled to the difference channel; the iajor portion of the energy is propagated in ie sum channel and is used by the PPI in the earch mode and for Pisa display in the height-nding mode.

ARGET HEIGHT GEOMETRY

The geometry of the target height-finding inction is shown in figure 14-28. The line-of-ight to the target R is developed by the radar et in the conventional manner through the sum hannel. Transmitter pulses strike the target nd are reflected back to the radar antenna. he time required for pulses to travel to the rget and back is measured, and since the propgation velocity of radio energy in space is nown the distance to the target is automatically omputed. The altitude of the AEW aircraft $_1$) is continuously monitored by the aircraft's nstruments. The true horizontal is determined y zero tilt stabilization of the antenna by a entral gyro reference system. Thus, only the ngle ϕ between the horizontal at the AEW airraft and the line of sight to the target is unnown. The radar set determines this angle y the inclusion of an additional channel of eception. Thus, there are two channels of dar reception which are designated the sum channel and the difference channel. Both channels are used to determine the angular position error between the antenna boresight axis and the line-of-sight to the target. Target echoes which are picked up by the antenna are applied to the sum channel. Part of the target echo, however, is sampled at the antenna feedhorn and propagated through the difference channel to the receiving circuits (fig. 14-25).

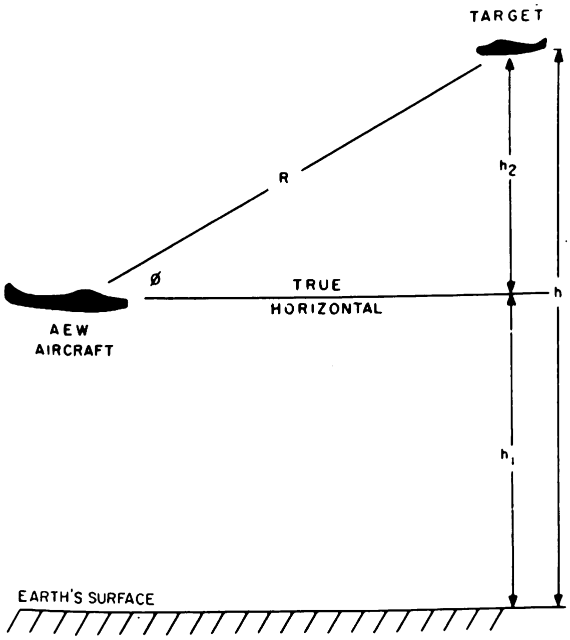


Figure 14-28. —Target height-finding geometry.

In the height-finding mode of operation, the sum and difference channel signals are detected and compared in the receiving circuits. The resultant signal is known as the MONO video (compared sum and difference video), which is applied with the sum video to the height finding system. The sum video develops the Pisa display on the height-finder scope. The mono video, which presents the angular position error between the antenna boresight axis and the line-of-sight to the target, is used to control the lean of the Pisa display. When the antenna boresight axis lies along the line of sight to the target, the mono video is zero and the Pisa display is horizontal. Any deviation of the antenna boresight axis from the line of sight to the target will result in either positive or negative mono video which will cause the Pisa display to lean either upward or downward. With the antenna alined with the target the antenna tilt angle (ϕ) is measured (fig. 14-28) and a simple trigonometric computation ($h_2 = R \sin\phi$), made automatically in the height indicator system, yields target height (h_2), which is added to AEW aircraft altitude (h_1) to yield target altitude (h). An additional correction is made by the computing circuits to compensate for the curvature of the earth, which is significant at the radar ranges and target altitudes involved.

Test Set AN/UPM-44B

Radar Test Set AN/UPM-44B is supplied as associate equipment to Radar Set AN/APS-82 and, therefore, is part of the AEW aircraft equipment complement, as well as the shore- or ground-based maintenance installation. A complete description of the radar test set is covered in the *Handbook of Service Instructions*, NavAer 16-30 UPM-44-502.

The radar test set consists of the test set assembly, transit case, and accessories. These are shown in figure 14-29. The equipment is designed for use with S-band radar systems.

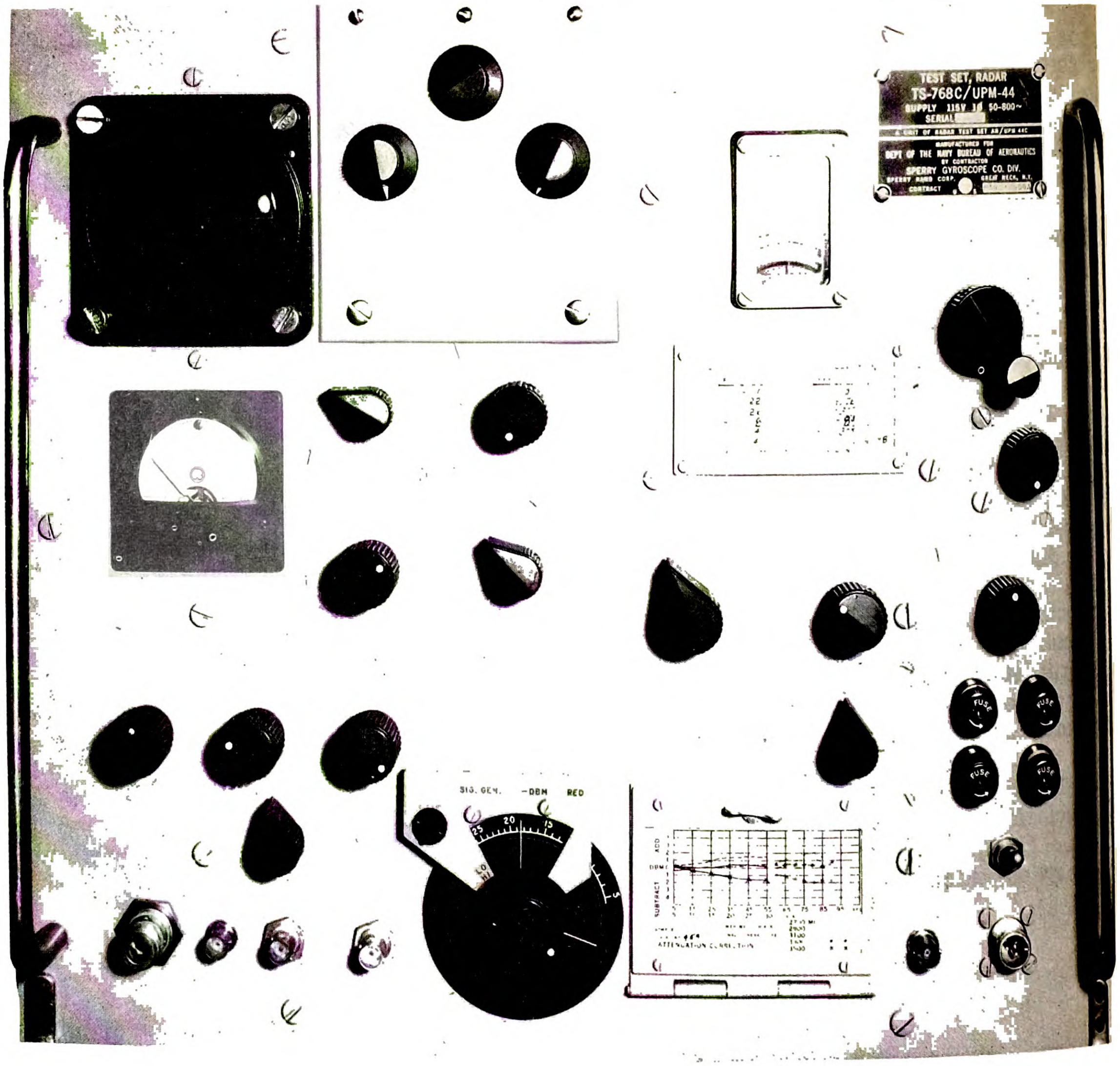


Figure 14-29.—UPM-44.

The test equipment may be used for the following purposes.

a. Measure receiver bandwidth sensitivity, recovery time, and local oscillator frequency.
b. Measure transmitter power and frequency.
c. Tune local oscillator.
d. Test and tune the duplexers, AFC system, and rotation joints.
e. Provide visual indication of the magnetron and local oscillator spectra.
f. Observe magnetron pulling.
g. Visual indication of video signals.

With the exception of frequency coverage, the UPM-44 is similar to the UPM-32. The UPM-32 is discussed in chapter 15.

SONAR

Sonar Set AN/AQS-4D is an airborne, dipping sonar system designed to detect underwater targets such as submarines. The equipment is designed primarily for installation in helicopters. In addition to aural and visual indication of targets, the AQS-4D provides for underwater CW communications with friendly submarines or surface vessels.

The major units of this sonar set are listed in table 14-1 and are also shown in figure 14-30. Of the major units shown, six are carried inside the helicopter. The seventh is the sonar dome which is suspended submerged in the water during operation. The dome houses the transducer and its training mechanism, the flux-valve compass, and the depth pressure potentiometer. The total weight of the system is less than 350 pounds. Only one operator is required.

Overall Operation

Detection is accomplished by echo-ranging or narrow-band passive listening operation. To prepare for operation, the sonar dome is lowered to the desired operating depth by means of the cable and cable reel assembly. This is done only while the helicopter is hovering. The dome may then be rotated in azimuth (trained), using either manual or automatic control.

Sonar Set AQS-4D will operate at any of three fixed frequencies. The operator selects the desired frequency by using the frequency selector switch, which is located on the front panel of the receiver-transmitter.

In echo-ranging operation, a pulsed, continuous-wave signal, adjustable in length, is transmitted by the transducer. The ultrasonic output frequency is generated by a stable crystal oscillator network in the transmitter. The transmitter is keyed, by keying relays controlled by the keying circuits in Range Recorder RD-46D/AQ.

The keying relays are actuated by a cam-operated switch in the range recorder. The cam is driven by the same motor that drives the writing helix; the rate of rotation of the helix and of the keying cam depends on the position of the RANGE K YARDS control on the range recorder.

TRAINING THE TRANSDUCER

Two modes of echo-ranging operations are possible—continuous manual training and automatic step-training.

Automatic step-training is usually used for systematic search of a relatively large area. In this type of operation, the bearing of the transducer is automatically changed in 10-degree steps before each pulse is transmitted. Thus a full 360 degrees in azimuth can be methodically searched in the time required to transmit 36 pulses (about 4-1/2 minutes in the 6,000-yard range). The sonar dome step-training is synchronized with the transmitter keying. A step-training pulse, initiated by a cam actuated switch in the recorder, actuates the step-training solenoid, which in turn rotates the training order synchro 10 degrees. The step-training pulse is initiated just before the keying operation.

In continuous manual training operation, the bearing of the transducer is controlled independently of the keying relay operation. The transducer is trained by the handwheel on the front

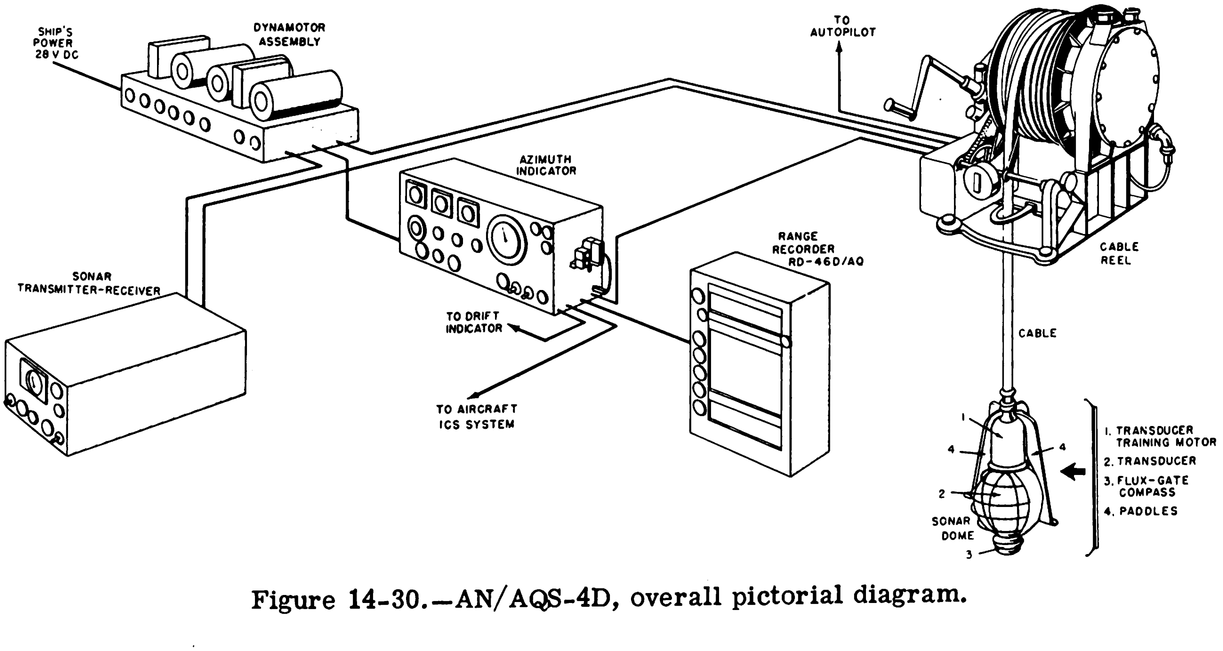


Figure 14-30.—AN/AQS-4D, overall pictorial diagram.

Table 14-1.—Major units of Sonar Set AN/AQS-4D

AN Nomenclature		Overall Dimensions (inches)			Weight (pounds)
Name	Type	Length	Width	Height	
Sonar Receiver-Transmitter	RT-200D/AQS-4	17 1/2	9 1/2	7	19.0
Azimuth Indicator	ID-319D/AQS-4A	10	17 3/4	10 1/8	31.5
Range Recorder	RD-46D/AQ	7 3/4	8 1/4	12	15.0
Sonar Dome	CW-219C/AQS-4	19 1/4 (diam)		31 1/4	44.0
Sonar Transducer	AT-280C/AQS-4	4 1/2	12 1/8 (diam)		28.0
Cable Reel	RL-152C/AQS-4	29 1/4	20 1/4	24	83.0
Cable Assembly, Electrical Special Purpose	CX-2320A/U	90 ft.	1 (diam)		58.0
Dynamotor Assembly	DY-73D/AQS-4	10 1/8	16	7	36.0

panel of the azimuth indicator. A selected bearing or azimuth sector may thus be searched more intensively than is possible in the automatic step-training mode.

Training orders to the sonar dome in both modes of echo-ranging operation are supplied to the training motor through a closed-loop servomechanism training control circuit. The servomechanism is basically a conventional circuit having a training order synchro (synchro control transformer) as the error measuring device, a servoamplifier, a dome training motor, and a flux-valve compass as the sonar dome position transmitter. As previously stated, training orders are introduced mechanically to the training order synchro by means of the training handwheel or the step-training mechanism. At the same time, sonar dome position information voltage is supplied to the training order synchro by the flux-valve compass. Any difference between the ordered and actual bearing of the dome appears at the output of the training order synchro in the form of an a-c bearing error signal. The error signal is amplified by the servoamplifier, detected and converted to the proper d-c signal by a phase detector, and presented to a magnetic power amplifier. The output of the magnetic amplifier is presented to the dome training motor, which drives the transducer to the ordered bearing. Paddles that are attached to the dome assembly extend into the water and prevent the dome housing from rotating. Therefore, when the proper bearing is reached, no error exists and the system is in equilibrium.

TRANSMITTING THE PULSE

The transmitter is comprised of a tuned amplifier, a driver, and a power output stage. When the crystal oscillator network and the final amplifier in the sonar transmitter are keyed a pulsed signal is developed. After being amplified by the transmitter, the electrical pulse is presented to the transducer for conversion to sound energy and transmission. Barium titanate ceramic elements in the transducer convert the electrical energy into sound energy. To obtain wide coverage during each transmission, the acoustical energy is propagated in a relatively broad-beam pattern.

During ultrasonic communications operation, the keying circuits are actuated by a hand key on the right side of the azimuth indicator. In this type of operation, the maximum power output is reduced by a power reduction circuit to prevent damage to the receiver-transmitter.

RECEIVING THE ECHO

Any echos reflected back to the transducer from acoustically opaque objects are converted into electrical signals and presented to the sonar receiver. The receiver is a fixed-tuned, highly selective superheterodyne circuit comprised of an ultrasonic amplifier, a converter, one IF amplifier, a diode detector, a BFO (beat frequency oscillator), and two stages of audio amplification. Manual and automatic gain control circuits are also incorporated in the receiver. The receiver amplifies the input signals and converts them to 800-cycle tones for presentation to the range recorder and azimuth indicator.

Simultaneous visual and aural target indications are provided. Visual indications are displayed on the SONAR LEVEL meter of the azimuth indicator and on the range recorder. Aural indications are presented by headphones connected to the azimuth indicator. The received audio signals presented to the range recorder

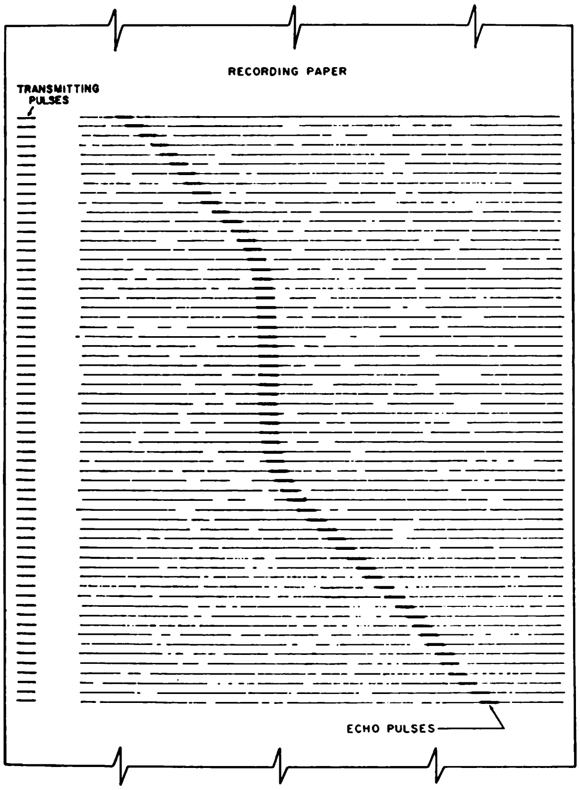


Figure 14-31. —Typical record from range recorder.

re amplified, rectified, and applied across the ecorder writing blade. The signal current ssing through the recording paper from the riting blade to the helix makes a permanent pression on the chemically treated paper, shown in figure 14-31.

Circuit Analysis

YING CIRCUITS

In echo ranging operation, circuits in Range corder RD-46/AQ-4 control both the pulse te and the pulse duration. Keying is accomshed mechanically by a motor-driven cam ich actuates keying switch S802. (See fig. -32.) When S802 is actuated, relays K101 K102 in Sonar Receiver Transmitter RT-/AQS-4 are actuated, thereby keying the nsmitter. The duration of the transmitted se is determined by a resistance-capacitance) pulse length control circuit. The writing ix and the cam are driven through a gear in by a d-c motor B801, the speed of which is ulated by a centrifugal governor.

The spur gear and drive motor drive a long pinion which is the power takeoff for the remainder of the gear train. Gear-train speed is controlled by a transmission. Selection of transmission gear ratios, corresponding to the desired range, provides speed control of the writing helix, switching cams and paper feed.

The keying cam, directly linked to the writing helix, initiates the transmission cycle by actuating microswitch S802. This action simultaneously applies a 250 volt d-c energizing voltage to relay K802 through dropping resistor R807 and charges capacitors C801 and C805 in the pulse-length control circuit. When cam rotation returns S802 to its normal position, keying relays K101 and K102 in the receiver-transmitter are energized, initiating the transmitted pulse. The duration of the transmitted pulse is controlled by the discharge time of C801 in parallel with C805. The pulse length can be varied by adjusting R817, the PULSE LENGTH control.

TRANSMITTER CIRCUITS

In both echo-ranging and communications operation, the high-power sonar transducer excitation pulses are generated in the transmitter section of the receiver-transmitter unit. Figure 14-33 shows a block diagram of the transmitter section.

The transmitter output frequency is generated by a beat-frequency oscillator network comprised of two stable, crystal controlled, oscillator stages and a pentagrid mixer tube. This network is pulsed at the selected repetition rate by a keying pulse derived from the keying circuits as discussed before. The output of the network is a series of low power excitation pulses occurring at the repetition rate selected by the recorder.

TEST-OPERATE switch S101 is incorporated with this network for driver and receiver testing, alinement, and adjustment. When S101 is in the TEST position, the oscillator network functions as a CW signal generator. Plate potential is applied through S101 to tuned amplifier V102A, which acts as a cathode follower output stage. The amplified CW signal is picked off the cathode of V102A and supplied to the receiver input, permitting accurate receiver alinement at the transmitter frequency.

During normal transmitter operation, V102A functions as a conventional, tuned triode amplifier. Plate potential is applied through keying

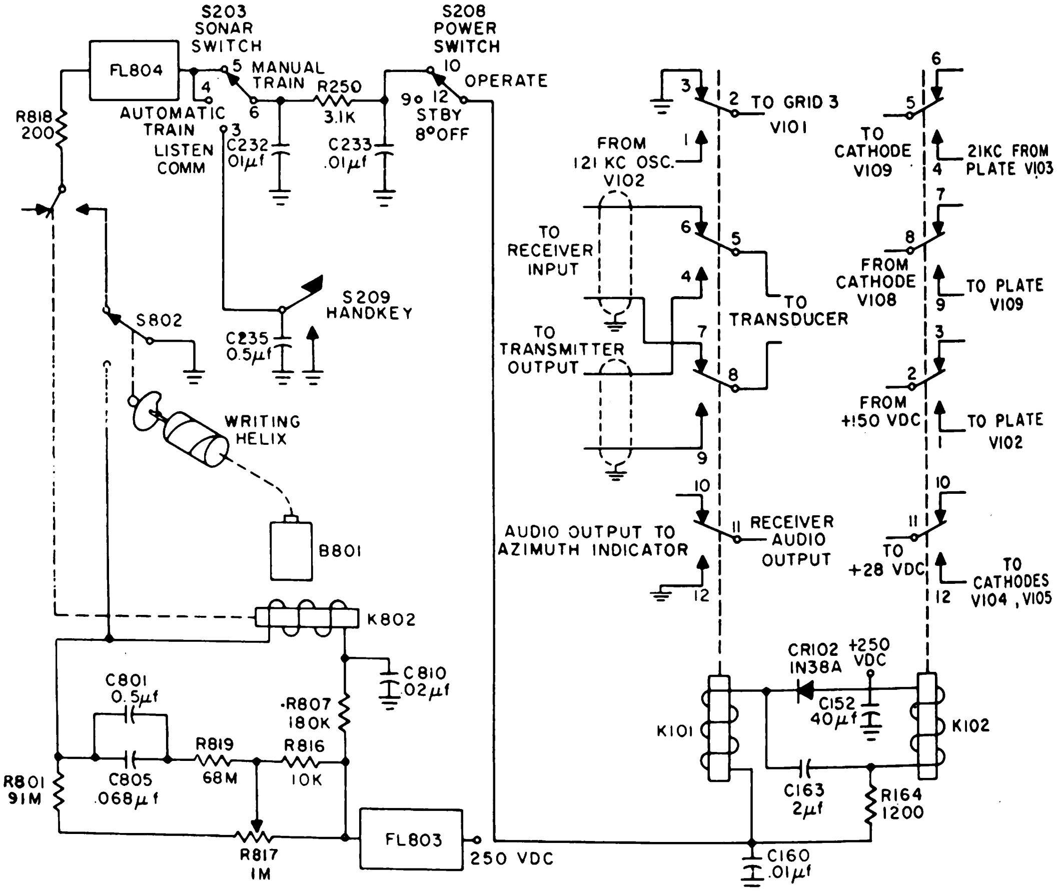


Figure 14-32.—Simplified schematic of keying circuits.

relay K102 to assure positive driver keying action. The relatively low power excitation pulses at the output of V102A are further amplified by driver-amplifier V103. The output of V103, a conventional beampower amplifier circuit, is transformer-coupled to the power output stage through driver transformer T101 and is also delivered through keying relay K102 to the receiver reverberation-controlled gain (RCG) circuit.

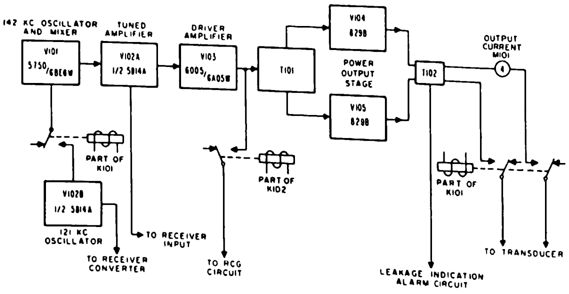


Figure 14-33.—Sonar transmitter, block diagram.

The power output stage employs two beam-power amplifier tubes connected in push-pull to develop the high-power excitation pulses.

TRANSDUCER

The high power pulses of electrical energy developed by the transmitter are converted into acoustical energy and propagated by Sonar Transducer AT-280C/AQS-4. This assembly is mounted inside the spherical section of Sonar Dome SW-219C/AQS-4. In figure 14-34 the face of the transducer is visible behind the protective grill of the sonar dome. The active elements of the transducer are barium titanate ceramic cylinders. These cylindrical elements have a mean diameter of 2.7 inches and are 0.7 inch long. Ten of these ceramic elements, arranged in a flat-face pattern, are mounted in cavities in

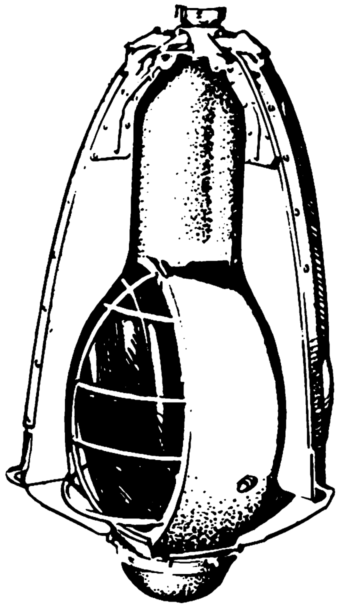


Figure 14-34. —Sonar dome.

a corprene retainer. The transducer assembly is covered by an acoustically transparent rubber diaphragm, evacuated and filled with dry, technical grade castor oil. Castor oil is used because its acoustic characteristics most nearly match those of sea water and therefore provide a matching medium between the transducer elements and sea water with minimum loss.

Operation of the transducer is based on the piezoelectric effect produced in the ceramic elements by the application of an electrostatic field or mechanical pressure. During transmission, the high power pulses of electrical energy are converted into pulses of acoustical energy at an ultrasonic frequency, and transmitted through the castor oil and rubber diaphragm into the sea water. During reception, acoustic signals striking the outside surface of the transducer are transmitted through the castor oil to the elements and produce electrical voltages. These voltages are produced in the elements by the varying mechanical pressure of the sound waves. The electrical signals are then supplied to the receiver.

A matching transformer is employed to match the transducer to the low impedance (75 ohms) transmitting and receiving circuits. The matching transformer is mounted inside a watertight compartment on the back of the sonar dome casting.

RECEIVER CIRCUITS

During reception, the relatively weak acoustic target echo signals impinging upon the transducer are converted into electrical signals. These are delivered to the receiver section of the receiver-transmitter unit for amplification and conversion, first to IF signals and then to 800-cycle audio signals. These audio signals are supplied to the presentation circuits (AUDIO OUTPUT meter, headphones, range recorder, and optional wire recorder).

Receiver gain is controlled both manually and automatically. Manual gain control is by means of the SONAR GAIN control on the azimuth indicator which varies the cathode bias of the ultrasonic amplifier and the IF amplifier. Automatic gain control is provided by a combination of RCG/TVG (reverberation-controlled-gain and time-varied-gain) circuits.

Since the receiver operates at fixed frequencies, no front panel tuning controls are required except for the FREQ (KC) switch for selecting the operating frequency. The receiver is alined to the proper operating frequency by use of the CW output signal derived from the oscillator in the transmitting circuits.

Both internal and external means of alining the receiver to the proper operating frequency are provided. For internal alinement, the TEST-OPERATE switch on the front panel is placed in the TEST position and the CW signal developed across the oscillator network V101 and V102 (fig. 14-33), permits alinement of the receiver without the use of an external signal generator.

For external alinement of the receiver, the output of an external signal generator is injected through the SIGNAL GEN jack. This method facilitates preinstallation bench testing of the equipment, but is not desirable for final alinement procedures because there is a possibility of not alining the receiver to the exact transmitter frequency. Exact alinement is assured only by use of the internal method.

A block diagram of the receiver section of Sonar Receiver-Transmitter RT-200D/AQS-4 is shown in figure 14-35. Ultrasonic amplifier V112 is a conventional, transformer-coupled pentode amplifier. The target echo signals derived from the transducer are applied through relay K101 to the primary of an input transformer. These signals are amplified by V112 and applied through a coupling transformer to converter V111, where they are combined with

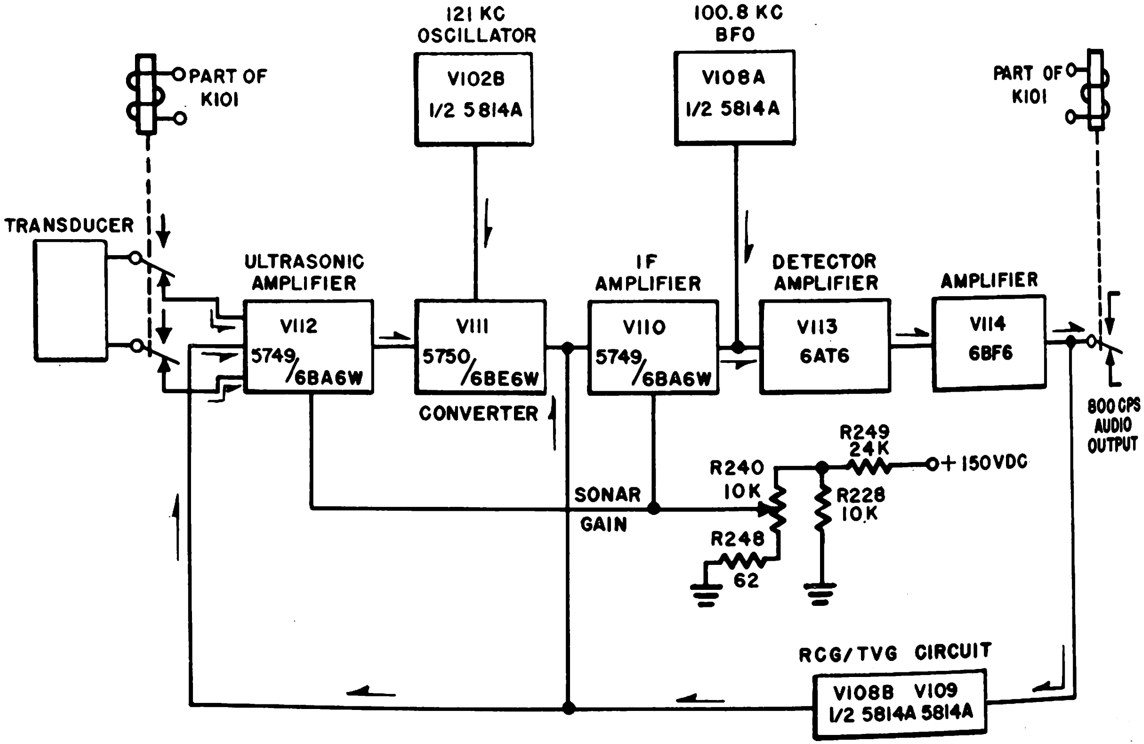


Figure 14-35.—Sonar receiver, block diagram.

a signal from V102B to produce the IF signals. Note that V102B is the local oscillator previously mentioned in conjunction with transmitter circuits. This circuit arrangement minimizes receiver tracking problems; if the transmitter frequency is altered, the receiver frequency is simultaneously changed.

Intermediate frequency amplifier V110 is a highly selective amplifier stage. The bandpass of this stage is approximately 250 cycles wide at the half-power point, which provides a highly selective IF stage with a good signal-to-noise ratio. BFO V108A and detector V113 convert the IF signal into an 800-c.p.s. audible signal by heterodyne action and rectification. Diode detection is used for combined high efficiency and circuit simplicity. BFO V108A is a conventional crystal-controlled Pierce oscillator. Both the IF signal and the BFO signal are applied to the plates of duo-diode V113. The rectified 800-c.p.s. difference is coupled to the grid of audio amplifier V114 through an RC network.

The amplified 800-c.p.s. output signal developed at the plate of V114 appears across the primary of an audio output transformer and is also coupled to amplifier V109B in the RCG circuit. The 800-c.p.s. audio signal derived from the secondary of the output transformer is delivered to the SONAR LEVEL meter, the audio switching circuits, and to the range recorder through keying relay K101.

RCG/TVG CIRCUIT

Automatic receiver gain is provided by a combination RCG/TVG circuit, shown in figure 14-36. Time-varied gain is controlled by the rectified driver output pulse, wherein the receiver gain is automatically reduced and allowed to return to a level selected by the manual gain control during a time interval controlled by the circuit time constant. Then reverberation-controlled gain action, controlled by rectified audio signals obtained from reverberations immediately following the outgoing pulse, is allowed to modify the receiver gain recovery in proportion to the intensity of reverberations.

Thus, the relative fast recovery curve of the TVG circuit is slowed down by the RCG action so that reverberations following the outgoing pulse will not overload the receiver. This feature also prevents operator fatigue from the

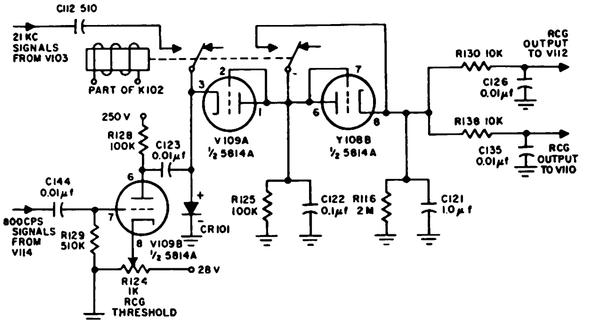


Figure 14-36. —RCG/TVG circuit, simplified schematic.

high noise level that would otherwise be present.

Visual target indications are continuously displayed on the SONAR LEVEL meter and permanently recorded by the range recorder. When the INTERCOM switch is in the SONAR position, audio output signals are supplied through headphones and also to an external wire or tape recorder if desired.

The audio signals from the receiver are supplied through keying relay K101 directly to the SONAR LEVEL meter, the output jacks on the azimuth indicator, and to the range recorder. The SONAR LEVEL meter continuously indicates the amplitude in decibels of the received signal.

TRAINING CONTROL CIRCUIT

A training control circuit, composed of a closed-loop servomechanism, is incorporated in the azimuth indicator to provide continuous control of the horizontal rotation of the transducer. To minimize noise due to turbulence at the face of the transducer, the free-flooding ball section of the sonar dome is rotated as a unit. Thus the water immediately surrounding the transducer itself is relatively calm during rotation.

The closed-loop servomechanism, figure 14-37, is basically a conventional circuit having a synchro control transformer as the error measuring device and a flux-valve compass as the transducer bearing transmitter. Transducer training orders are introduced mechanically into the servomechanism through the rotor of control transformer B202 either from the step-training mechanism or by means of the handwheel on the front of the azimuth indicator.

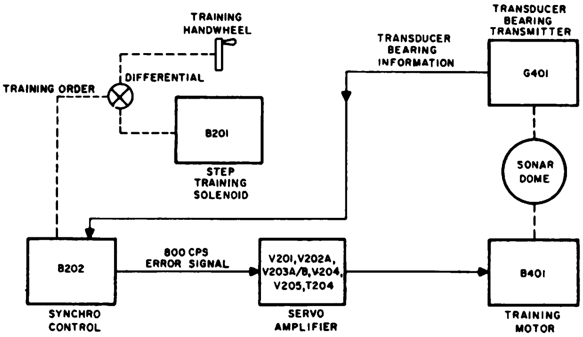


Figure 14-37. —Servomechanism, block diagram.

The rotor of the control transformer is mechanically linked to a compass dial-bearing indicator on the front panel of the azimuth indicator. Thus, the ordered transducer bearing is continuously displayed to the sonar operator. A variation adjustment incorporated in the compass dial indicator provides for insertion of compass variation correction.

Transducer bearing information is supplied to the stator of control transformer B202 by flux-valve compass G401, which is mounted on the bottom of the ball section of the sonar dome. The characteristics of the compass are such that the output voltages are developed at twice the frequency of the input voltage. In this circuit, the input voltage to the compass is a portion of the 400-c.p.s. a-c system voltage. Hence, the frequency of the output voltages to the stator of B202 is 800 c.p.s. The 800-c.p.s. error signal developed across the rotor of B202 during training operations is supplied to the servoamplifier.

In the servoamplifier, the error signal is amplified, compared with an 800-c.p.s. reference voltage, and converted into a d-c error signal by a phase-sensitive detector circuit. The d-c error signal is further amplified by two balanced d-c amplified stages and employed to control the operation of the power output stage.

To minimize the weight of the amplifier chassis and increase mechanical ruggedness, a magnetic amplifier power output stage is used. This eliminates the necessity for a high-voltage, high-current power supply circuit and lowers the overall weight of the equipment. The output of this stage supplies the excitation voltage for the controlled field of the training motor.

The ball section of the sonar dome is driven through a compound planetary gear train by a two-phase a-c training motor. As previously stated, excitation voltage for the controlled field of the training motor is supplied by the servoamplified output, and excitation voltage for the fixed field is supplied by the 400 c.p.s., a-c system voltage. Since the servoamplified output signal is a function of the input error signal and is thus dependent on the initial transducer bearing error, the sonar dome ball section is automatically rotated in the direction required to reduce the error.

INDICATION CIRCUITS

One of the equipment features is a depth and cable length indication circuit. DEPTH meter M202 on the azimuth indicator shows the depth of the sonar dome.

A bridge circuit is used as the means of measurement for height and cable indications. Figure 14-38 shows that this circuit is controlled by two special potentiometers—a conventional one with a special taper which is actuated when the reel drum turns, and a pressure-actuated potentiometer in the sonar dome, actuated by water pressure. Source voltage for the circuit is the 150 volt d-c supply line.

To provide positive indication that the sonar dome is submerged below the surface of the water, there is an indication circuit employing a blue DOME SUBMERGED lamp, I205, located on the azimuth indicator. Variations in voltage across R401, the depth-pressure potentiometer, provide the dome-submerged indication.

When the wiper of R401 is a ground (sonar dome not in the water) the plate current of V206B is high, energizing K204. When K204 is energized, the DOME SUBMERGED lamp is not lighted. Relay K203 is energized, opening the 115 volt, 400 c.p.s. power circuit to the sonar dome training circuit. This interlock prevents training the sonar dome when it is not submerged in water. When the sonar dome is submerged to the correct depth, the wiper on depth-pressure potentiometer R401 moves toward a more positive potential, thereby reducing the plate current of V206B and de-energizing K204. When K204 is de-energized, the DOME SUBMERGED lamp is lighted and power is applied to the training circuits. Should it be necessary to operate the training circuits while the sonar dome is not submerged, relay K203 may be de-energized by setting SERVO PWR switch S210 in the TEST

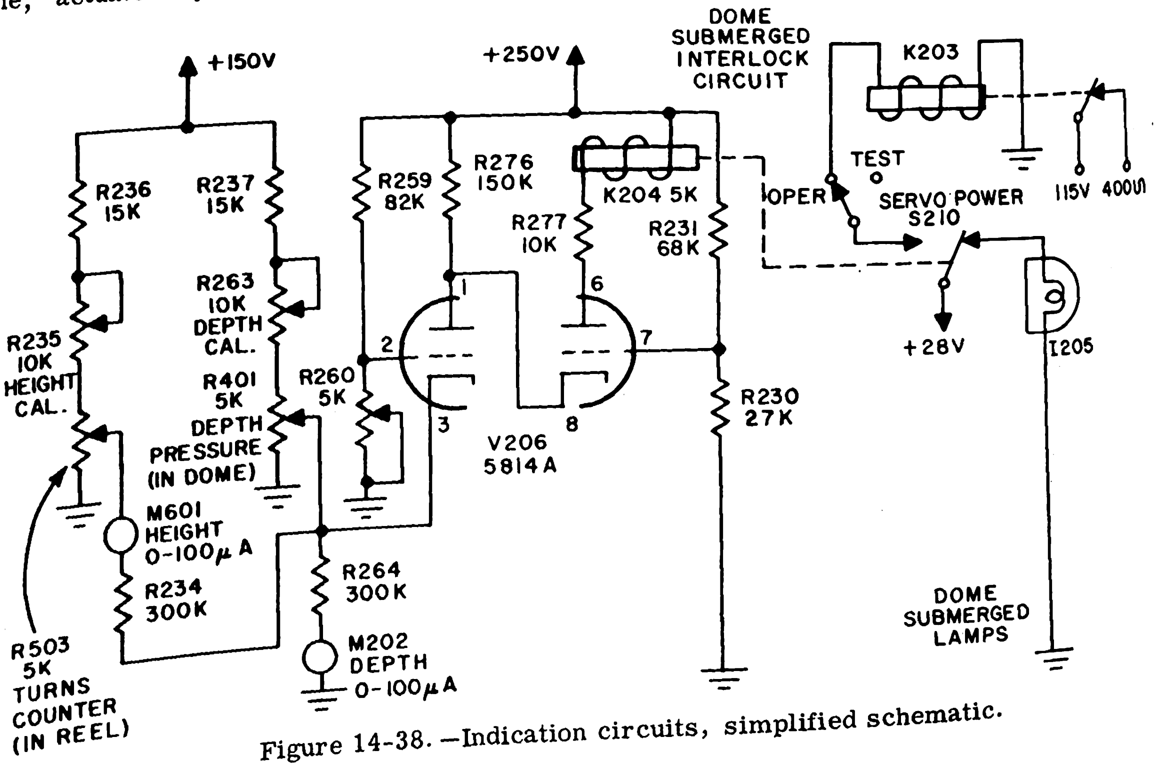


Figure 14-38. —Indication circuits, simplified schematic.

position. At all other times S210 should be in the OPERATE position.

LEAKAGE INDICATION

This circuit provides immediate indication of the presence of moisture at the sliprings in the top section of the sonar dome or at the sonar transducer connection. The indication is displayed by a neon bulb LEAKAGE indicator on the front panel of the azimuth indicator.

To conserve space and weight, a modified phantom circuit is employed for the leakage indication circuit. This circuit uses the driven excitation pulse transmission circuit between the receiver-transmitter and the sonar transducer as the primary circuit. One terminal of the LEAKAGE indicator is connected through a current limiting resistor to the 150 volt, d-c operating voltage. The other terminal is connected to the center-tap of driver output transformer T102 (fig. 14-33) in the transmitting circuits. Hence, when either of the signal leads is grounded by moisture or if enough moisture eaks into the slipring assembly, firing voltage s applied and lights the LEAKAGE indicator.

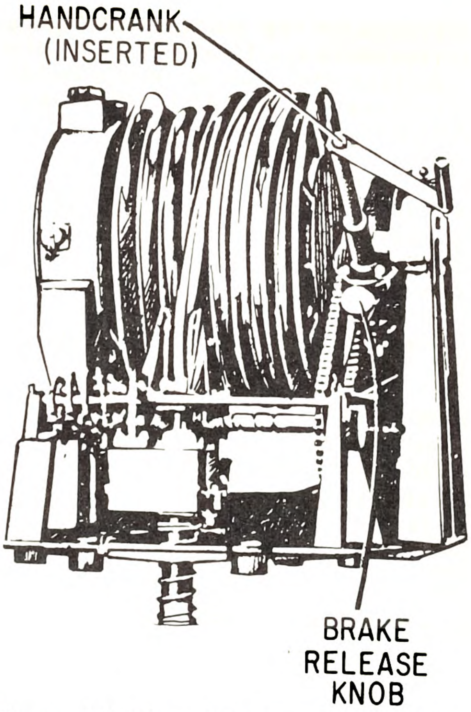


Figure 14-39. —Cable reel assembly, protective cover removed.

Mechanical Operation

Cable Reel RL-152C/ASQ-4 is a compact ioist capable of lowering and raising the sonar lome from the hovering helicopter. The cable eel is composed of a drum on which the cable s wound, a drive motor and associated gearing, manual (emergency) hoisting mechanism with a motor cutout switch, a level-wind, cable-laying device, a cross-fork drift sensing mechanism and a brake release knob for use when the manual hoist is employed. The cable reel is mounted on a raised platform, as shown in figure 14-39.

Controls and associated indicators for operation of the cable reel are located on the front panel of the azimuth indicator, allowing the sonar operator to control the position of the dome.

QUIZ

1. The AN/ARC-52 operates in which of the following frequency ranges?
   a. HF
   b. VHF
   c. UHF
   d. SHF

2. The AN/APS-82 accurately displays the height of any airborne target
   a. above sea level
   b. above terrain
   c. on a conventional PPI presentation
   d. on a B-scope presentation

3. The RF energy transmitted from the doppler radar navigation set will be
   a. reflected back at the same frequency
   b. a modulated signal
   c. a CW signal
   d. used for altitude information

4. The crystal transducer used in the AN/AQS-4D changes electrical energy into acoustical energy and vice-versa, by employing the
   a. magneto-striction principle
   b. piezoelectric effect
   c. concept of unlike objects attracting each other
   d. characteristic of allowing current to flow in only one direction

5. The monopulse technique
   a. transmits two pulses 90° out of phase
   b. transmits two pulses 180° out of phase
   c. divides the echo pulse into two pulses
   d. utilizes a beacon station for the second pulse

6. The AN/ARC-52 differs from the AN/ARC-27 in that it
   a. offers more possible total frequencies
   b. offers less possible total frequencies
   c. has twice the output power in watts
   d. operates at a higher frequency

7. The kind of bearing information indicated by the transducer bearing indicator is
   a. magnetic only
   b. relative only
   c. true only
   d. either magnetic or true

8. Referring to figure 14-38, assume that R 231 has opened. Symptoms that might result from this trouble are:
   a. dome submerge lamps will be lit at all times, but no power will be applied to the training motor
   b. dome submerge lamps never light, and both height and depth indicators read in error
   c. no apparent change in the operation of the equipment
   d. height and depth indicators read correctly, but dome submerged indicators do not light until a depth of 50 feet is reached

9. The AN/APS-82 operates in the______band
   a. X
   b. S
   c. K
   d. L

10. The tone oscillator used in the AN/ARC-52
   a. can only operate at 1,000 c.p.s.
   b. is of the Butler type
   c. is of the RC type
   d. is of the Hartley type

11. The output from the crystal mixers in the doppler radar navigation set will be
   a. the sum, difference, and the two input frequencies
   b. the difference frequency only
   c. the sum frequency only
   d. always an RF frequency

12. The Ground Speed and Drift Angle Indicator in the doppler radar navigation set is used to
   a. combine the V_h and V_d information
   b. indicate the airspeed and course
   c. furnish information to the signal data converter
   d. measure the distance to the station

13. (Refer to fig. 14-38.) When the dome is in the water, the transducer will not train, and the dome submerged lamps do not light. Height and depth indicators read in error. A possible cause is that
   a. R230 has opened (right of V206)
   b. S210 is in the TEST position (above and right of V206)
   c. the solenoid of K203 has opened (above and right of V206)
   d. R231 has opened (above and right of V206)

14. The AN/AQS-4D equipment is keyed on "Echo-ranging" operation by
   a. a sawtooth generator
   b. a pulse from a multivibrator
   c. a cam operated switch
   d. the step-training motor

15. The output signals from the signal data converter in the doppler radar navigation set will be
   a. d-c voltage, either positive or negative
   b. a-c voltage, of variable phase
   c. analog voltage representing airspeed
   d. two analog voltages proportional to doppler frequency

16. The electron tube liquid cooler is needed to
   a. cool the high voltage power supply
   b. cool the groundspeed computer
   c. keep the antenna system cool
   d. keep the klystron cool

17. In automatic step training search operation, the bearing of the transducer is automatically increased in increments of ______ degrees
   a. 5
   b. 10
   c. 15
   d. 20

18. Hand keying is usually incorporated in sonar equipment to provide
   a. sector scan for search operation
   b. communication between sonar operators
   c. tracking of a known target
   d. emergency operation in case of automatic keying failure

9. A memory signal is used in the doppler navigation set to
   a. stop the computation process when the signal is lost
   b. store information until it is needed
   c. hold the equipment in a search condition
   d. allow the equipment to have a wider range

0. The purpose of the altitude data transmitter is to
   a. keep track of the altitude at all times
   b. measure the change of altitude
   c. transmit altitude information to the ground
   d. measure the altitude of a target

21. The purpose of the ground speed computer in the doppler radar navigation set is to
   a. display the groundspeed
   b. compute the airspeed
   c. compute heading velocity and drift velocity
   d. generate a 400 c.p.s. signal to represent airspeed

CHAPTER 15

TEST EQUIPMENT AND MAINTENANCE TECHNIQUES

As a senior shop petty officer, one of your most important duties is to maintain a constant quest for ways to improve the working efficiency of the men you supervise. There are many ways in which this can be done. For instance, you can obtain and pass on to the men information on and ways of using special test equipment, information concerning troubleshooting shortcuts and maintenance techniques, and so forth. This type of information is usually not found in the *Handbook of Maintenance Instructions* for the aircraft.

This chapter provides information on the operation and use of certain test equipment generally not used daily, but is highly useful when needed. It also includes a few items of information pertaining to special maintenance and troubleshooting problems that may be noted and passed on to your men. There is a vast amount of such information available. It is not practical to list all of it in this training course. The few items and ideas listed here are intended only as a sample of the TYPE of information for which you should watch and listen. For instance, you should be a regular reader of such publications as the *Electronics Digest*, *Naval Air News*, and the various command publications since they contain much information of this nature. Any improvement you are able to make in the working effectiveness of your men adds directly to the performance record of your whole organization.

Special Maintenance Problems

As the ceiling for aircraft on extended flights has been raised higher and higher, many new types of operating and maintenance problems have developed. Some of the various types of equipment involved are generators, voltage regulators, electric motors, and solenoids. Electric brushes on generators, inverters, electric motors, and other rotating electrical machinery wear away very rapidly at high altitude (around 40,000 feet). Special brushes have been developed that have longer life at high altitude. Thus, it is advisable to use the proper type brushes and to check them more frequently when high altitude flying is being performed.

While most switches will break a circuit safely at sea level, their contacts may burn and in some cases even melt at high altitude. It has been found that double-break contact switches somewhat alleviate this fault. Since electric and electronic systems use special design switches for high altitude operation, when making a replacement it is necessary to use the proper type.

Other items that often fail during high altitude flights are electrical plugs and receptacles. A voltage breakdown occurs between the pins and shell along the surface of the insulating material. The result is a burned plug. This happens because the breakdown voltage is less at high altitude. For example, the breakdown voltage for a 1/4-inch air gap is about 3.7 times greater at sea level than at 40,000 feet.

This condition may be overcome by sealing the connector with a potting compound. This reduces the probability of arc-over between pins or between pins and the shell of the electric connector since the dielectric characteristics of the connector are improved. This sealing compound will also protect the connectors from corrosion or contamination by excluding metallic particles, moisture, and aircraft liquids. For information regarding the application of a sealing compound consult the current publication on this subject.

ADVERSE ENVIRONMENTAL AND CLIMATIC CONDITIONS

In recent years the effect of environmental conditions upon the operation of electronic and electrical equipment has greatly increased the naintenance problems of the technician. These peculiar conditions may be grouped under the najor headings of altitude, temperature, and umidity. At the extremes of these conditions special maintenance and operating procedures re required. Equipments required to function t these extremes frequently fail due to the ef- ect of decreased air density, radical tempera- ure changes, and moisture.

Continuous damp, warm air causes conden- ation of atmospheric moisture within equipment nless units are hermetically sealed or the in- eriors are maintained at a temperature higher hen surrounding atmospheric temperatures. ondensed moisture forms leakage paths and auses corrosion. These climatic conditions romote rapid fungus growth which in itself has corrosive effect on materials, such as wire, witch contacts, and other metal parts.

Humidity is a term describing the amount water vapor in the air. It is usually expressed s a percentage of the total amount of water the r can hold at a given temperature. Thus, 50 ercent means the air contains one-half the total ater it can hold, and 100 percent means it con- ins all it is capable of holding. Air can hold ore water as its temperature increases. In opical areas the humidity varies between 60 d 100 percent. This high humidity accounts r the condensation of moisture, or sweating, on rious parts of electronic equipments when ey undergo temperature changes. Condensed oisture on insulating materials reduces their sulating qualities and results in arc-overs and orts between terminals. The water vapor also netrates into the body of insulation, is ab- rbed, and causes similar effects. High humid- also causes corrosion of metals. Other sources of moisture which cause deterioration include fog, salt spray, and rain.

In general, equipment may encounter extreme temperatures, ranging from minus 65° F. to a maximum of 135° F., under various climatic conditions of high humidity, fog, rain, salt spray, salt air, cold, insects, fungi, and dust. High temperature and moisture vapor cause rapid corrosion. Fungus and bacterial growths produce acids and other products which speed corrosion, etching of surfaces, and oxidation. This interferes with the operation of moving parts, screws, and so forth, and causes dust between terminals, capacitor plates, and other parts, which produces noise, loss in sensitivity, and arc-overs.

Variations of temperature cause moisture to be breathed through any small cracks, pinholes, or vents in the equipment. As the temperature rises, the air inside a piece of equipment expands and it is expelled, in part, through the openings and vents. When the temperature falls, the air inside the equipment contracts and outside air is admitted through all openings and vents. The moisture which is breathed destroys the insulating qualities of dielectrics and corrodes metals.

Fungus is a form of plant life which feeds on materials of vegetable and animal origin including paper, cotton, and so forth, and such things as dead insects and other fungi. These may be spread by wind, dust, dirt, and insects, such as ants, flies, and mites. Growth may take place on materials other than those of organic origin if a spot of dust or other nutrient substance is present. Fungi thrive in the high humidities and temperatures. Fungus growth causes decay, accelerates the deterioration of insulating materials, and short circuits items such as relays, jacks, and keys. The inclusion of a fungicidal compound in the manufacture of the equipment retards the growth of these fungi.

Most new equipment is given a climatic deterioration prevention treatment which provides a reasonable degree of protection against fungus growth, moisture, corrosion, salt spray, insects, cold, desert heat, and so forth. The treatment involves the use of a lacquer or varnish coating material applied with a spray gun or brush. Detailed instructions dealing with this treatment may be found in the *General Instructions Handbook*, T. O. No. 16-1-41.

RADIO NOISE INTERFERENCE

Suppression of radio interference is a task of first importance to maintenance personnel. The problem has increased in proportion to the complexity of both the electric system and the electronic equipment. The aircraft, the engine, the electric system, and the electronic equipment are involved in the problem. Almost every component of the aircraft is a possible source of radio interference, which is the main factor in preventing the operation of receivers at full sensitivity. All personnel concerned should be familiar with the problem of radio noise and how to eliminate it.

The overall effect of radio interference of any kind is to impair or deteriorate the performance and reliability of radio and electronic sets or systems. The interference may act directly by actual deterioration of the equipment response, or indirectly by wearing down the patience and tolerance of the human operator. Either way, the result is the same, since combat efficiency is materially reduced.

You should know the following:

1. What radio interference is.
2. Where the interference originates.
3. How it gets into equipment.
4. How to identify it.
5. How to suppress it at its source.
6. How to segregate its path of entry into a receiver.
7. How to prevent its entry into a receiver.
8. What considerations enter into the design of an interference-free equipment.
9. How to position and install electrical and electronic devices.

This information is presented in detail in the publication, *Reduction of Radio Interference in Aircraft*, NavAer 16-1-521. Some of the most important of this information will be presented briefly in the following pages.

Sources of Radio Noise

The origin or sources of radio noise are divided into three general groups. These are atmospheric static, precipitation static, and man-made radio noise.

Atmospheric static, or "atmospherics," is a burst of RF energy caused by electrical discharges in the atmosphere. Although the frequency spectrum of atmospheric static is very wide, only frequencies in and below the high-frequency band propagate far enough to be very troublesome at long distances from the electrical disturbance. Therefore, UHF and VHF receivers are seldom troubled by atmospheric static. Reduction of such static is obtained by use of frequency modulation, directional antennas, and noise-limiter circuits. Frequency modulation is not used extensively in aircraft radio communication because of the bandwidth requirements.

Precipitation static is caused by the development of large static charges on the aircraft when it is flown through snow, rain, ice crystals, or dust clouds. An aircraft can build up a charge of several hundred thousand volts in a few seconds. The resulting high voltage gradients at extremities and sharp points exceed the breakdown strength of air and cause noisy corona discharges. The conventional radio antenna, which must stand away from the body of the aircraft to be of effective height, is exposed to high electric fields. This means that corona discharges occur first in the antenna system, the very place that is most sensitive to noise. Precipitation static is reduced by using a completely insulated antenna system—that is, by using highly insulated wire instead of bare wire, and by insulating all connections and supports for the antenna wire. Precipitation static is reduced also by eliminating all sharp metal projections from the aircraft and by installing dischargers, which quietly discharge accumulated static charges at a high rate. A discharger consists of silver-impregnated cotton wicking encased in a flexible plastic tube with an aluminum mounting lug. The many fine high-resistance fibers provide a multitude of discharge points. The resulting discharges are quiet up to very high currents. For detailed information on precipitation static refer to NavAer 16-1-518, *Handbook Installation and Maintenance Instructions, Anti-Precipitation Static System.*

The effect of precipitation static is a loud hissing or frying noise from the speaker or headset of radio equipment and interference (grass) on the picture tube of visual output receivers. As an AT you should be concerned with precipitation static since it is produced only when the aircraft is flying. Also, the preventive measures that are taken are the primary responsibility of your rating. You should be aware of its characteristics for there is the probability that you will have to correct for radio interference that is caused by precipitation static. Unless you know its characteristics you will not be able to determine that the equipment for which you are responsible is not causing the trouble.

Manmade radio noise is caused by electrical transients which occur during the operation of electrical or electronic equipment. In brief, manmade radio noise will be generated whenever an electrical circuit is opened or closed abruptly, such as by a relay, commutator, or other make-and-break devices. A similar condition exists when large amounts of current are periodically and abruptly started and stopped, as in radar circuits. An electric spark is a generator of electrical disturbances which appear to cover the entire radiofrequency spectrum.

The principal sources of manmade radio interference in aircraft are rotating electrical machinery, switching devices, pulsed electronic equipments, transmitter spurious emission, ignition systems, propeller control systems, receiver oscillators, nonlinear elements, a-c power lines, and voltage regulators. As an AT you will not be concerned with all of these sources. Those with which you should be familiar are briefly discussed.

1. ROTATING ELECTRIC MACHINES are a major source of radio interference. The types of interfering voltages generated by d-c machines are: (1) Switching transients as the brush moves from one commutator bar to another. This is usually called commutation interference; (2) Random transients caused by varying contact between brush and commutator. This is usually called sliding contact interference; (3) Audiofrequency hum (commutator ripple), and (4) Radiofrequency and static charges built up on the shaft and rotor assembly.

Direct-current motors used in aircraft systems are of three general types: series wound, shunt wound, and permanent magnet field. The field windings of both series- and shunt-wound motors afford some "padding" or filter action against transient voltages generated by the brushes. The permanent-magnet motor's lack of such inherent filtering makes it a very common source of interference. It must be emphasized that the size of a d-c motor has little bearing upon its interference generating characteristics. The smallest motor aboard may well be the worst offender.

The output of an ideal a-c generator is a pure sine wave. A pure sine wave voltage is incapable of producing interference except at its basic frequency. However the ideal waveform is difficult to produce, especially in small machines. Practically all types of a-c power generators currently used in naval aircraft have been proven to be potential sources of interference at other than the output power frequencies. This interference is produced in the form of (1) harmonics of the power frequency, caused by poor waveform, (2) commutation interference (series-wound motors), and (3) sliding contact interferences (alternators and series-wound motors). It should be noted that a-c motors that do not use brushes are almost never sources of interference.

2. SWITCHING DEVICES make abrupt changes in electric circuits. Such changes are accompanied by transients capable of interfering with the operation of radio and electronic systems. The simple occasionally operated manual switch is of little consequence as a source of interference. Examples of frequently operated switching devices capable of appreciable or serious interference are relays, vibrators, and thyratrons.

Since relays are used almost exclusively to control large amounts of power with relatively small amounts of power, they are always potential interference sources. This is especially true when they are used to control inductive circuits. Relay actuating circuits should not be overlooked as interference sources, because even though the actuating currents are small, the inductances of the actuating coils are usually quite high. It is not unusual for the control circuit of a relay to produce more interference than the controlled circuit.

Induction vibrators are essentially double-pole double-throw relays which operate at a constant rate. As in any induction type switch or relay, there are two sources of switching transients, the inductive field contacts and the switching contacts. The output waveform of the vibrator is essentially rectangular at some audiofrequency. Its harmonic content is high and filtering is difficult.

Because of its interfering capabilities, the vibrator is seldom used as a radio power source in naval aircraft except for certain commercially available radio equipments found in small auxiliary aircraft. The principal use of inductive vibrators in naval aircraft is in connection with jet engine ignition systems.

Thyratrons are gas filled, grid controlled, electronic switching tubes which are used for many purposes. Among the most common uses are keyer tubes in radar modulators, rectifiers in regulated power supplies, rectifiers in servo systems, and relay applications. The current flow in a thyratron is either all ON or all OFF; there is no in-between. Since the time required to turn a thyratron ON is only a few microseconds or less, current waveforms in thyratron circuits are always steep fronted. As a result, they are rich in radio interference energy.

3. A NONLINEAR ELEMENT may be defined as a conductor or semiconductor whose resistance or impedance varies with the voltage applied across it. Nonlinear elements thay may cause radio interference in aircraft, in the order of their commonness, are overdriven vacuum tubes, oxidized or corroded joints, cold solder joints, and unsound welds. In the presence of strong signals a nonlinear element behaves as a detector or mixer, producing harmonics and sum and difference frequencies from signals applied to it.

4. ALTERNATING-CURRENT POWER SOURCES produce radio interference of a broadband nature. In a-c powered equipments, a-c hum may appear at the power frequency or at the rectification ripple frequency. The ripple frequency of a full-wave rectifier is twice the power frequency times the number of phases. Normally, aircraft systems utilize only single- and three-phase sources at 400 c.p.s. Full-wave rectification of single-phase, 400 c.p.s. power gives a ripple frequency of 800 c.p.s; a three-phase source yields 2,400 c.p.s. This ripple can produce interference varying from annoyance to complete unreliability of equipment, depending on its severity and its coupling to susceptible elements.

Suppression of Manmade Radio Noise

Suppression of radio noise has advanced to the point where the proper application of available techniques will insure that receiving equipment installed in the aircraft will operate at optimum efficiency. The suppression or elimination of manmade radio noise is based on the premise that if manmade it can be man-corrected. Four types of suppression techniques are involved.

Isolation is the easiest and most practical method of radio noise suppression and revolves around the possibility of separating the source of radio noise from the input circuits of the receiving equipments affected. As every radio noise source can be considered a small transmitter, it is obvious that the radio noise source and leads carrying radio noise energy should be kept as far away from receiver antennas or lead-ins as possible. In many cases, the radio noise in a receiver may be entirely eliminated simply by moving the antenna lead-in wire just a few inches away from the source of radio noise. The value of sufficient separation between sources of radio noise and receiver input circuits is not apt to be over-emphasized. The isolation method of radio noise suppression is very popular as it has the advantages of not requiring any additional material or adding any additional weight.

Bonding is a very necessary means of radio noise control. It provides grounding of all insulated conducting objects on the exterior of the aircraft. When conducting objects are not grounded, flight through precipitative weather conditions causes high-voltage charges to build up on those objects. Repeatedly, the voltage gets high enough to spark over to an adjacent ground member or the object discharges to the surrounding air by corona conduction. Either mode of discharge causes considerable radio noise.

Other important functions of bonding are to protect the aircraft and personnel from lightning discharges by equalization of potentials produced which might cause arcs and sparks in the aircraft structure, to provide a homogeneous counterpoise for radio transmission and reception, to provide power current return paths, and to provide a short path for bypassing RF noise. All electronic equipments should be grounded to the aircraft structure. This will be done by using short bond straps or by sheets of high conductivity (copper or aluminum) metal where it is impossible to use a short bond strap. No bond strap should be more than four inches in length.

Shielding is one of the most effective methods of suppressing radio noise. The primary object in shielding is to electrically "bottle up" the radiofrequency noise energy. In practical application, this means that the radio noise energy must be kept flowing along the inner surface of the shield. The use of good shielding is particularly effective in situations where filters cannot be used and are not particularly effective when they are used. A good example of this is where radio noise energy radiates from a radio noise source and the radiated energy is picked up by the various circuits that eventually connect to the receiver input circuits. It is obvious that it would be impractical to filter a number of leads or units that are influenced by the radio noise energy; hence, the application of effective shielding at the noise source itself is advisable for it will eliminate the radiated portion of the radio noise energy by confining it within the shield at its source.

Radio interference as radiated or conducted from a source may be of a single frequency or may cover an extended band of frequencies. When bonding, shielding, or isolation of the source proves ineffective as a means of reducing radio interference, it becomes necessary to employ filters to accomplish this reduction. A filter is defined as "a selective network which transmits freely electric waves having frequencies within one or more frequency bands and which attenuates substantially electric waves having other frequencies." The size of a filter may vary widely depending on the voltage and current requirements as well as the degree of attenuation desired. Filters are usually incorporated in equipment known to generate radio interference, but these filters are often inadequate, and in many cases it is necessary to add filters external to these equipments. This is especially true if the source of interference is coupling interference to paths of entry to a receiver other than the power line.

The types of filters used in the reduction of radio interference vary with the application, but each of the general filter types may be found to be particularly adaptable to some specific situation. Most of the electrical devices connected to power lines have features required for their operation, which are conducive to the generation of radio interference. The interference generated by these devices, unless properly attenuated, is impressed upon the power lines and conducted to the receivers. It may also be conducted into the receivers by inductive coupling to other wiring associated with the receivers. This interference, unless attenuated by means of filters, is then transmitted along these power lines, entering the receivers at the power line input; or this interference may be radiated somewhere along the power lines and enter the receiver by means of the antenna system.

Filters are of four kinds and are defined as follows:

LOW-PASS FILTER, which introduces negligible attenuation at all frequencies below a certain frequency, called the cutoff frequency, and relatively high attenuation at all higher frequencies.

HIGH-PASS FILTER, which introduces negligible attenuation at all frequencies above a certain frequency, called the cutoff frequency, and relatively high attenuation at all lower frequencies.

BAND-PASS FILTER, which introduces negligible attenuation at all frequencies within the range between two frequencies, and relatively high attenuation at all other frequencies.

BAND-ELIMINATION FILTER, which introduces negligible attenuation at all frequencies outside a certain range, and relatively high attenuation at all frequencies inside that range. (NOTE: For information that covers the theory of operation of these filters refer to NavPers 10087, *Basic Electronics.)*

The normal characteristics of a filter are obtained only when the filter is properly terminated in its characteristic impedance.

A wave trap is a filter or network especially designed to reject certain frequencies, or bands of frequencies. Networks of this type may be installed at the antenna of the transmitter or receiver in order to attenuate frequencies outside of the assigned frequency range of the equipment. All such networks must have low insertion loss, or attenuation, for the pass frequencies. In the design and construction of wave traps, the insertion loss is usually below 2 db.

There are two basic circuit configurations for filter networks, the pi-section and the T-section. Each may be broken down into half sections which have an inverted L-shape and are known as L-section filters. If a number of pi- or T-sections are connected in series to form a filter, the resultant network is called a ladder network. Any of the above circuit configurations may be used for radio interference elimination.

In general, the use of simple capacitor filters is to be preferred over that of the more complicated network filters in cases where this type of filter provides the required degree of radio interference attenuation. In this method, the radio noise energy passes through the capacitor to ground and then back to its source. This short-circuiting effect is due to the fact that the capacitor offers a very low impedance path across the noise source terminals.

A given capacitor is effective in bypassing only a limited range of radio interference frequencies because of its internal inductance and the inductance of the connecting leads. The inductance of the capacitor depends upon its capacity, the material of which it is fabricated, and the length of the connecting leads. The capacitor leads are the major contributors to the inductance of capacitors. For these reasons, small mica capacitors with short leads are more effective as filters at high frequencies than large paper capacitors with normally long leads. Electrolytic capacitors should never be used as filters because of the danger of dielectric breakdown.

The popularity of the capacitor type filter is due to the fact that the current used for operation of the radio noise source does not have to pass through the filter. The only energy passing through the filter is the radio noise energy. The most important limiting factor in the choice of a capacitor-type filter is the breakdown voltage rating of the capacitor. It must be well above the voltage used to operate the source of radio noise to be filtered. For example, where a 24-volt source of noise is to be bypassed with a capacitor, the working voltage of the capacitor should be at least 50 volts.

DEFINITIONS FOR AIRCRAFT ELECTRONICS

Oftentimes it is difficult to understand just what someone has in mind when he is referring to electronic equipment. Terms such as component, part, subassembly, assembly, unit, group, set, system, accessory, and attachment are used to describe this equipment. One person will use one of these terms when referring to a particular equipment and another will use another of the terms to refer to the same equipment. This results in confusion and misunderstanding.

BuAer Instruction 10550.14A sets forth standard definitions for electronic equipment. The information that follows defines the various terms and gives examples of their application. (See fig. 15-1.)

An accessory is a part, subassembly, or assembly designed for use in conjunction with or to supplement another assembly, or a unit or set, contributing to the effectiveness thereof without extending or varying the basic function of the assembly or set. An accessory may be used for testing, adjusting, or calibrating purposes.

An attachment is defined as a part, subassembly, or assembly designed for use in conjunction with another assembly or a unit or set, contributing to the effectiveness thereof by extending or varying the basic function of the assembly, unit, or set.

Maintenance Techniques

BRUSH CONTOURING DEVICE

In order to receive optimum performance from rotating machines that utilize brushes, it is important that the brushes make proper contact with the commutator or sliprings. Inspections of generators and motors have revealed that faulty operation is caused in many cases because the brushes do not properly fit the commutator or sliprings. This could be caused by the brushes having not been properly run-in when they were installed.

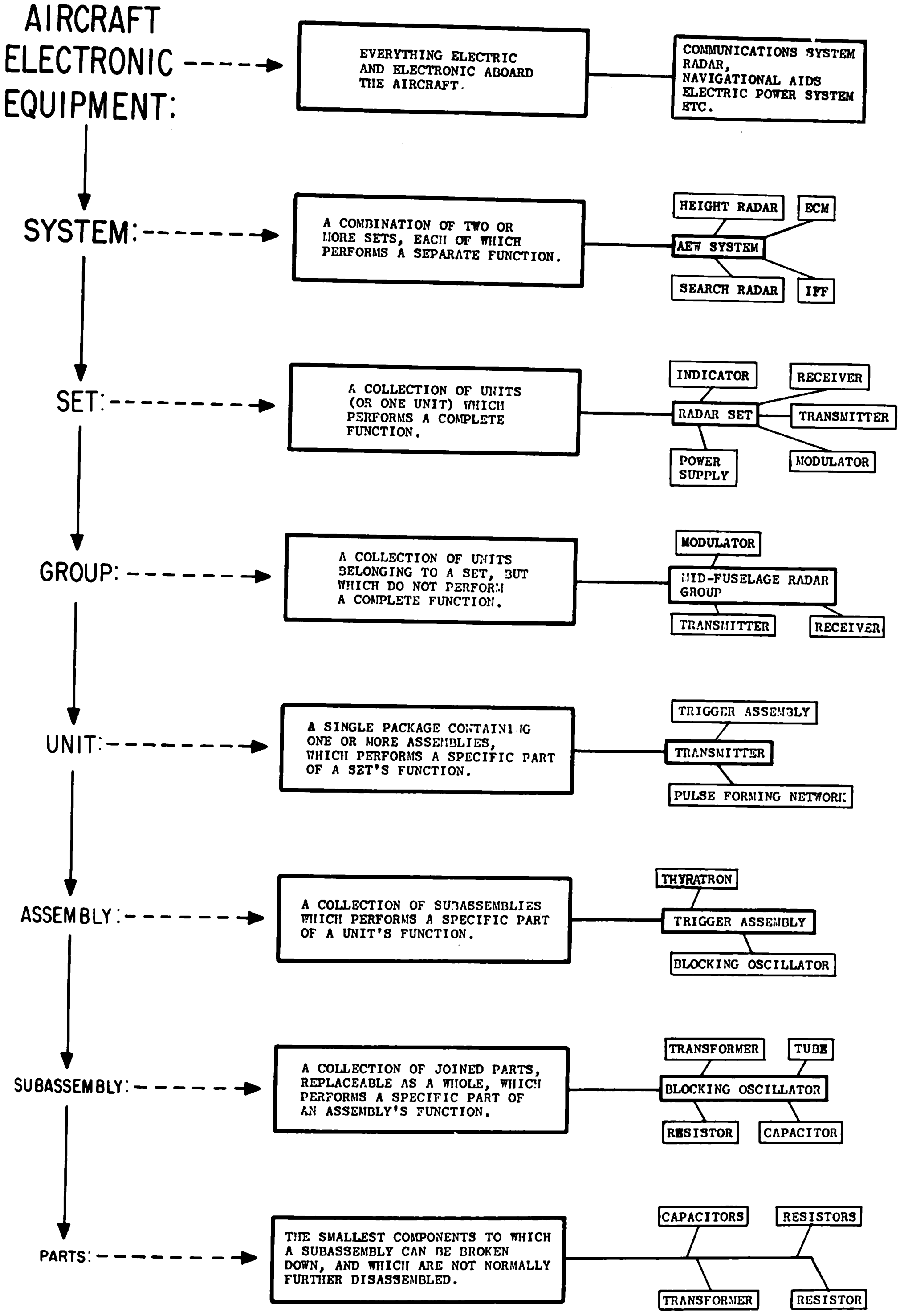
The discussion that follows describes a brush contouring device that can be easily constructed at most electric shops. If properly used, it will insure proper brush seating and also save much time. Should you decide to construct one of these devices you may not want to follow the exact procedure that follows. However, the information that is given should prove helpful as a guide.

Figure 15-2 shows the disassembled parts that are needed for constructing the device and figure 15-3 shows an assembled view.

The following materials are needed (refer to fig. 15-2):

1. One piece of laminated plastic (A) 4 x 6 x 1/2 inch.
2. One brass disk (B), one inch thick, drilled in center to receive bolt for mounting.
3. One piece of angle aluminum (C) 1 x 1 x 2 1/2 inches.
4. One piece of 1/8 inch plastic (D) 2 1/2 x 3 inches.
5. One bolt (E) for mounting disk and two instrument mounting screws. One of these screws to be fitted with a wingnut.

Part (B) must be turned on a lathe since its diameter is critical. This part must be the same diameter as the commutator or slipring for which the brush is being fitted.



AIRCRAFT ELECTRONIC EQUIPMENT: EVERYTHING ELECTRIC AND ELECTRONIC ABOARD THE AIRCRAFT.

SYSTEM: A COMBINATION OF TWO OR MORE SETS, EACH OF WHICH PERFORMS A SEPARATE FUNCTION.

SET: A COLLECTION OF UNITS (OR ONE UNIT) WHICH PERFORMS A COMPLETE FUNCTION.

GROUP: A COLLECTION OF UNITS BELONGING TO A SET, BUT WHICH DO NOT PERFORM A COMPLETE FUNCTION.

UNIT: A SINGLE PACKAGE CONTAINING ONE OR MORE ASSEMBLIES, WHICH PERFORMS A SPECIFIC PART OF A SET'S FUNCTION.

ASSEMBLY: A COLLECTION OF SUBASSEMBLIES WHICH PERFORMS A SPECIFIC PART OF A UNIT'S FUNCTION.

SUBASSEMBLY: A COLLECTION OF JOINED PARTS, REPLACEABLE AS A WHOLE, WHICH PERFORMS A SPECIFIC PART OF AN ASSEMBLY'S FUNCTION.

PARTS: THE SMALLEST COMPONENTS TO WHICH A SUBASSEMBLY CAN BE BROKEN DOWN, AND WHICH ARE NOT NORMALLY FURTHER DISASSEMBLED.

Figure 15-1. —Definitions for aircraft electronics.

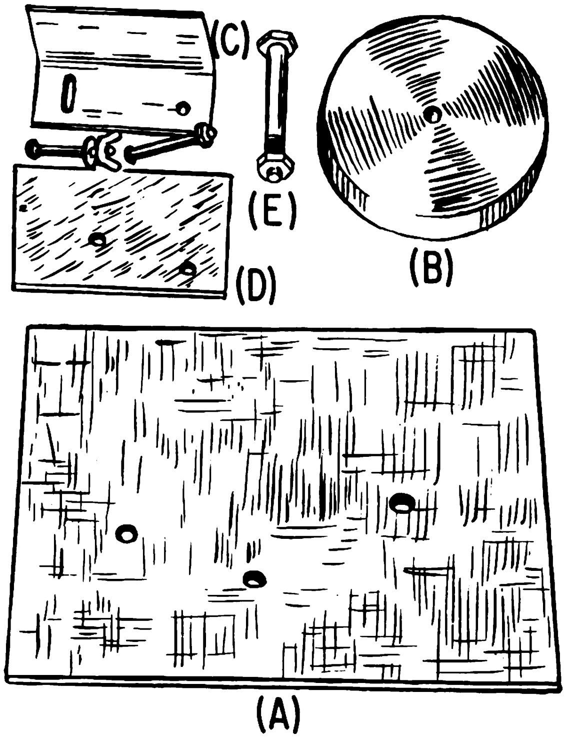


Figure 15-2. —Parts required for contouring device.

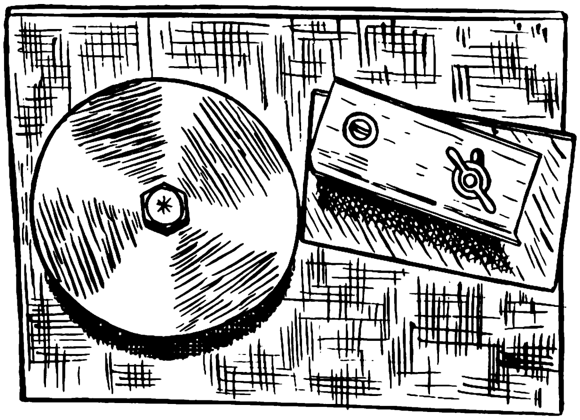


Figure 15-3. —Assembly of contouring device.

The following steps should be used when contouring brushes:

1. Loosen the adjusting bolt in the elongated slot in part (C).

2. Using an old brush removed from the generator, motor, or electrical starter, place brush against the angle aluminum, part (C), moving angle until brush contacts brass disk throughout its contoured surface. Lock part (C) with wingnut. CAUTION: Use properly seated brushes for step 2.

3. One person then holds a strip of very fine sandpaper, 1 inch wide, on outer diameter of brass disk, and pulls the ends alternately back and forth, keeping sandpaper taut. The other person holds a new brush against part (C) and pushes lightly against the sandpaper until the proper contour is formed on the brush end. NOTE: Be careful to keep brush tight against part (C) during contouring.

By contouring brushes with this device instead of in the generator, all carbon, dust, grit and so forth are kept out of the generator. Moreover, the brush surface will be contoured at the correct angle with respect to the longitudinal axis of the brush. With the device, less run-in time is required, there is less chance of generator failure due to brushes heating, and excessive commutator and slipring wear is eliminated.

TESTING AN CONNECTORS

In the course of normal troubleshooting, the AT very often has occasion to gain access to a circuit through an AN connector. These connectors are convenient for obtaining voltage checks, and for making resistance or continuity tests. In some cases, the connector itself is found to be faulty. Next to broken or faulty solder joints in the back of the connector pins, the most common fault of connectors is loss of internal contact between pins and receptacles. A receptacle may be "sprung" from a physical blow, or repeated connecting and disconnecting. When this occurs, the receptacle does not "grip" the pin with sufficient tension to maintain good electrical contact.

Connective tension may be checked by the use of test devices similar to the ones shown in figure 15-4. Old ignition lead connectors are used for handles in this case, but any other suitable material may be used. Inserted and secured within the phenolic handles are steel pins machined to the proper diameters shown in table 15-1. (Brass pins from spare connectors may be used, but they wear quickly.)

To use a test pin, it is inserted to its full depth in a receptacle, then pulled straight out, with no side pressure. A defective receptacle is

Table 15-1.—Connector pin sizes and separating forces.

Connector sizes	Pin size ±0.0001	Force in pounds	
		Maximum	Minimum
16	0.0625 in.	3	1/4
12	0.094	5	1/2
8	0.142	10	3/4
4	0.225	15	1
0	0.357	20	2

indicated by a lack of grip on the test pin. A spring scale, or weights of appropriate size, are used to make an accurate check. However, retracting-force requirements are quite broad, so that adequate "feel" may be developed, and thus speed up the work.

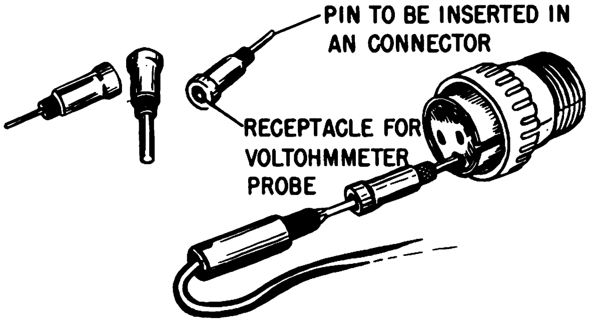

PIN TO BE INSERTED IN AN CONNECTOR
RECEPTACLE FOR VOLTOHMMETER PROBE

Figure 15-4. —AN connector and test device.

In addition to checking connective tension, the test devices may be used as adapters. Each test device may include a female receptacle in the end opposite the male testing pin. This receptacle is drilled to an inside diameter to accommodate the standard voltohmmeter test probe. By selecting the test device adapter with the correct size pin, a secure test connection may be made to any size connector receptacle. The voltohmmeter probe may then be inserted into the drilled receptacle; thereby, it will not have to be held by hand in a receptacle too large for it, nor will it "spring" a receptacle that is too small.

ELECTRICAL RELATIONSHIPS

Figure 15-5 shows formulas that can be used for determining electrical or associated relationships.

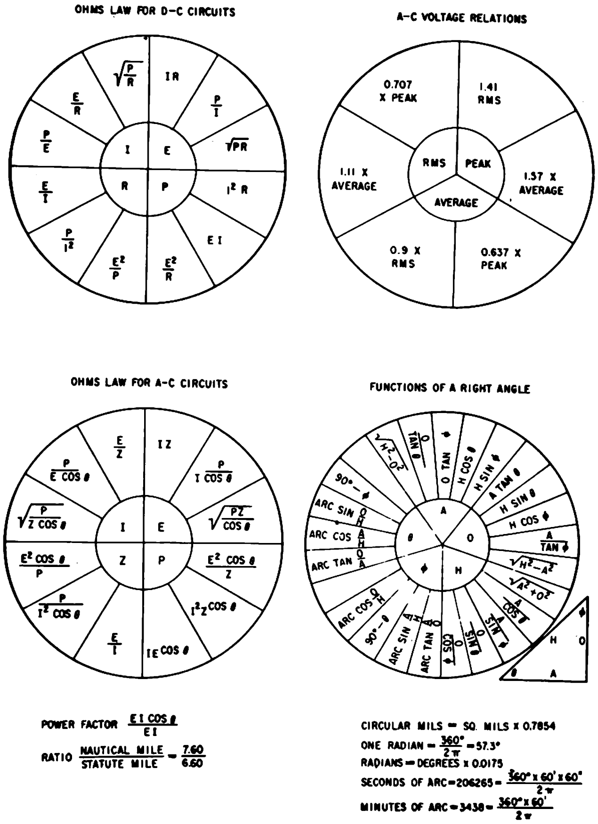

OHMS LAW FOR D-C CIRCUITS
I
E
R
P
A-C VOLTAGE RELATIONS
RMS
PEAK
AVERAGE
0.707 X PEAK
1.41 RMS
1.11 X AVERAGE
1.57 X AVERAGE
0.9 X RMS
0.637 X PEAK
OHMS LAW FOR A-C CIRCUITS
I
E
Z
P
FUNCTIONS OF A RIGHT ANGLE
A
O
H
θ
ϕ
POWER FACTOR $\frac{EI\cos\theta}{EI}$
RATIO $\frac{\text{NAUTICAL MILE}}{\text{STATUTE MILE}} = \frac{7.60}{6.60}$
CIRCULAR MILS = SQ. MILS x 0.7854
ONE RADIAN = $\frac{360°}{2\pi}$ = 57.3°
RADIANS = DEGREES x 0.0175
SECONDS OF ARC = 206265 = $\frac{360° \times 60' \times 60''}{2\pi}$
MINUTES OF ARC = 3438 = $\frac{360° \times 60'}{2\pi}$

Figure 15-5. —Electrical or associated relationships.

RADAR TROUBLESHOOTING

Efficient troubleshooting calls for an orderly, systematic plan of attack. No use leaping from one end of the equipment to the other end, guessing that "maybe the trouble is here". Troubleshooting requires a good understanding of the theory of operation of the equipment. A visual inspection should first be made. When making this inspection, look for discolored or burned resistors, corroded switch contacts, broken or frayed wires, gassy tubes, leaking electrolytic or oil capacitors, and loose mechanical assemblies. After making the visual inspection, refer to the *Handbook of Service Instructions*.

This publication contains circuit breakdown illustrations, tube socket voltage and resistance charts, and test bench procedure. All this information will prove helpful to the technician.

A list of helpful hints on radar troubleshooting follows:

1. It is generally advisable to take all measurements on all ranges of operation of a particular radar under test.

2. Always adjust the radar's crystal current before attempting a sensitivity check.

3. The frequency of magnetrons usually increases with a decrease in pulse width.

4. Recovery time decreases with a decrease of pulse width.

5. Recovery time decreases with an increase in receiver sensitivity.

6. Receiver sensitivity usually decreases with a decrease in crystal current.

7. Magnetron frequency decreases with an increase in reflected load from the antenna.

8. Frequency pulling by the antenna must be checked with the antenna in motion.

9. A magnetron which arcs under test can be the result of:

   a. The magnetron not conducting hard enough.
   b. Not enough warmup time.
   c. Low filament voltage.
   d. PRF too low.
   e. Pulse width too narrow.
   f. Excessive high or low line voltage.

10. Normally, returning the magnetron to standby to allow longer warmup time will stop the magnetron from arcing.

11. Local oscillators (klystrons) in radar receivers are usually operated above the magnetron frequency in search and below the beacon station frequency on beacon.

12. Intermittent troubles can usually be located effectively by placing several pieces of test equipment at several points in the radar under test. For example the trouble is intermittent targets. Possible causes could be crystal, duplexer, magnetron, IF strip, detector, video amplifiers, indicator, power supplies, or the antenna. In this case, where any one could very easily be the cause of the trouble, the following checks will help isolate the trouble:

a. A test scope on the video detector will show whether the trouble is the result of the magnetron, klystron, IF strip, detector antenna, or crystal. If the output here is constant, the trouble is in the video amplifiers or the indicator.

b. If the output at the detector is not constant, a meter connected to read magnetron current will show whether the magnetron is at fault. While watching the scope, see if the magnetron current is fluctuating as the targets are lost.

c. If the antenna is suspected, the targets will usually be intermittent at the same azimuth setting. If it is found that the targets do become intermittent at the same azimuth position of the antenna, the rotating joint will usually be the cause.

13. Low output power may be the result of:

   a. Low line voltage.
   b. Bad high voltage rectifiers.
   c. Poor magnetron.
   d. Pulse width too narrow.
   e. PRF too low.

14. Erratic AFC operation other than the AFC units may be the result of:

a. The antenna pulling the magnetron frequency, causing the AFC to fall out.

b. Magnetron frequency modulation.

c. Erratic operation of the local oscillator.

d. The AFC being set up on the slope of the klystron curve instead of at the top.

15. A little common sense, a basic knowledge, and proper test equipment, can make troubleshooting a radar as easy as troubleshooting a radio.

While power is important in determining maximum range, system gain is much more so, since the effect of the gain in increasing range is equal to the SQUARE of the effect of the power in increasing range. It is therefore important for the technician to keep the gain, or sensitivity, of the radar at the peak of possible performance. The radar receiver should be centered at the transmitter center frequency, and the local oscillator must be made to operate at the magnetron frequency plus the IF center frequency. The AFC circuits must be accurately alined to prevent loss of valuable system gain.

Test Sets for Radar Maintenance

For effective operation of an aviation radar system, it is imperative that its radar set operate at its maximum effectiveness within its designed limits. To accomplish this the technician must employ the best maintenance techniques and utilize the test equipment to the utmost.

The following discussion on the operation and circuitry of various radar test equipments is designed to aid the AT 1 & C in furthering his knowledge of these test equipments and their use in effective maintenance of aviation radar sets. The technician should bear in mind that this discussion is not a substitute for the test equipment's *Handbook of Operation Instructions* or *Handbook of Service Instructions*, which should be consulted before operating any type of test equipment.

UPM-55 PULSE GENERATOR

The UPM-55 system is basically a pulse generator and a synchroscope combined in one unit. Its purpose is to provide, display, and measure pulse test signals. The major units of the system are the pulse generator case, the pulse generator (SG-30/UP), various connector adaptors, and the necessary cable and cord assemblies. It is designed for portability and the maximum weight of the entire equipment is 110 pounds.

The main unit of the system is the pulse generator (SG-30/UP), which is housed in a metal cabinet. (See fig. 15-6.) It has been designed to furnish rectangular voltage pulses of adjustable duration, amplitude, and repetition frequency. These pulses follow the trigger pulses by an adjustable time interval. The equipment may be triggered by an external, or an internally generated audio signal. Internally generated pulse, trigger, and audio signals are made available at output terminals on the front panel. With the synchroscope provided in the same unit, the SG-30 is capable of accurately determining the waveshape amplitude, duration, and time relation of the output pulses.

In actual operation, voltage pulses from the pulse generator are coupled to the electronic equipment being tested. Output from the equipment under test is then fed back to the test unit where it is accurately measured by the synchroscope.

The general characteristics of the SG-30/UP are as follows:

1. Pulse duration . . . . . .0.2 to 20 microseconds.
2. Pulse amplitude . . . . .0.5 or less to 45 volts.
3. Pulse Repetition Frequency. . . . . . . .20 to 20,000 pulses per second.
4. Pulse delay . . . . .2 to 200 microseconds.
5. Trigger amplitude. . . .50 volts minimum.
6. Sweep duration. . . . . .1 to 625 microseconds.
7. Sweep delay. . . . . . . .2 to 200 microseconds.

To facilitate circuit analysis of the pulse generator it can be divided into five functional groups. The block diagram shown in figure 15-7 shows interrelationships of the circuits employed. The groups are as follows:

1. RC Oscillator.
2. Trigger generator.
3. Pulse generator.
4. Display and measuring circuits.
5. Power supply.

RC Oscillator

The RC oscillator has been incorporated in the equipment for the purpose of controlling the pulse repetition frequency of the output pulse. It is a basic Wein bridge RC oscillator with minor circuit modifications. By introducing a frequency sensitive element in the positive feedback, it is possible to control the frequency of oscillations. By switching resistors, it is possible to multiply the fundamental range of 20 to 200 c.p.s., allowing continuous coverage from 20 to 20,000 c.p.s. The oscillator is provided with an output control and an output connector and may therefore serve as an audiofrequency test oscillator.

Trigger Generator

The trigger generator (fig. 15-8) furnishes trigger pulse signals to the pulse generator for

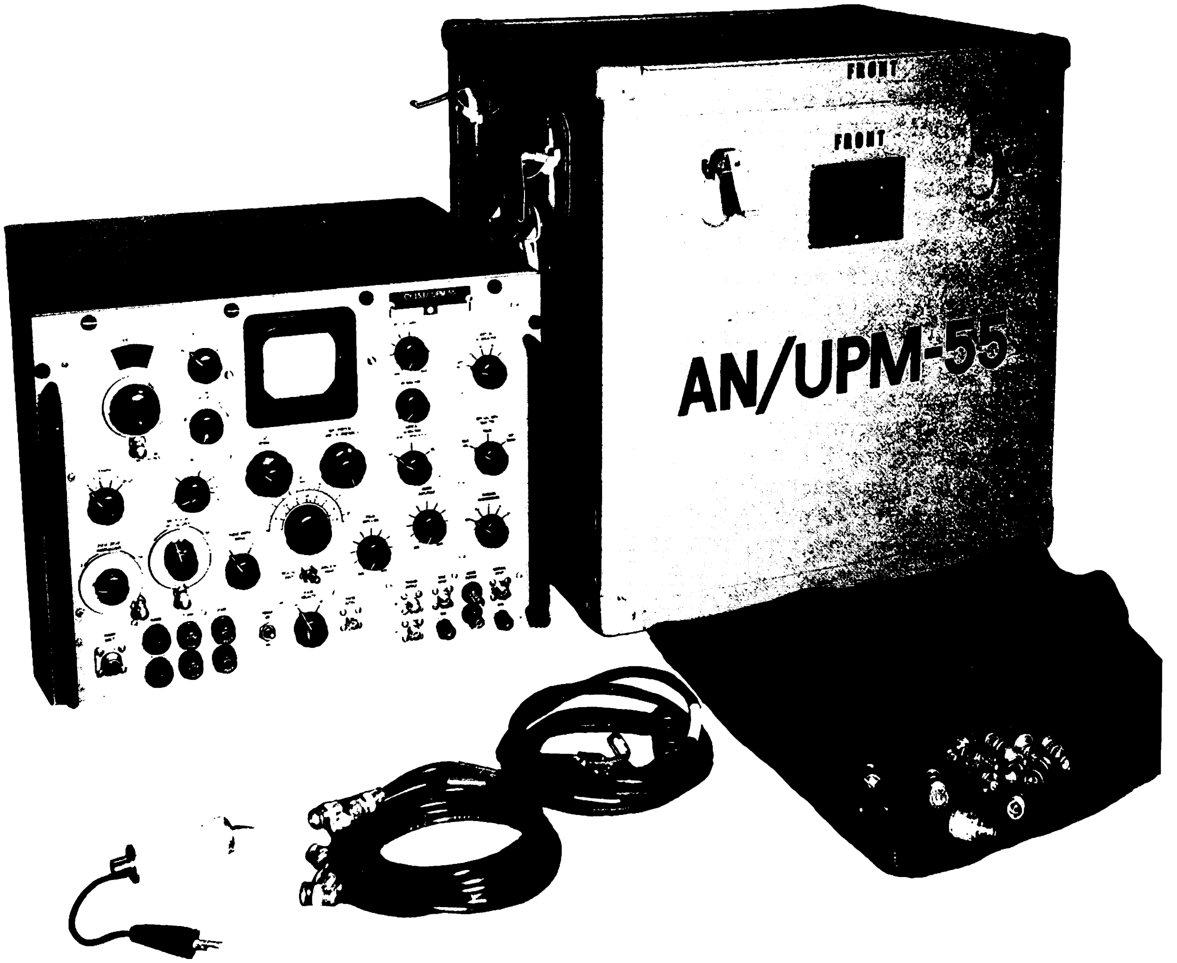


Figure 15-6. —Pulse generator AN/UPM-55

initiating output pulse signals and to the sweep generator circuits for initiating the horizontal sweep on the cathode-ray tube. The trigger generator circuit contains a shaper stage for converting the sine-wave output of the RC oscillator to a square wave. The square wave is then coupled to the trigger blocking oscillator, which furnishes the trigger pulses to the pulse and sweep generating circuits.

The function of V301, a 6BN6, as a pulse shaper is sufficiently unconventional to warrant special consideration. Figure 15-9 will be used in connection with the explanation of a 6BN6. This figure shows the beam distribution pattern of a 6BN6 under various grid potentials.

The cathode of a 6BN6 emits a focused beam of electrons in a manner similar to that found in a cathode-ray tube electron gun. These electrons are attracted to the plate, or to the collector, depending upon the potentials applied to the first and second grid elements. As the electrons leave the cathode, they are accelerated towards the first electrode, which may be considered as a "collector." This electrode has a physical construction similar to a box. The factor controlling electron flow through this box is the potential applied to the first grid. If the first grid is made a few volts negative with respect to the cathode, the plate current is completely cut off. Refer to figure 15-9 (A) and (C) for a pictorial diagram

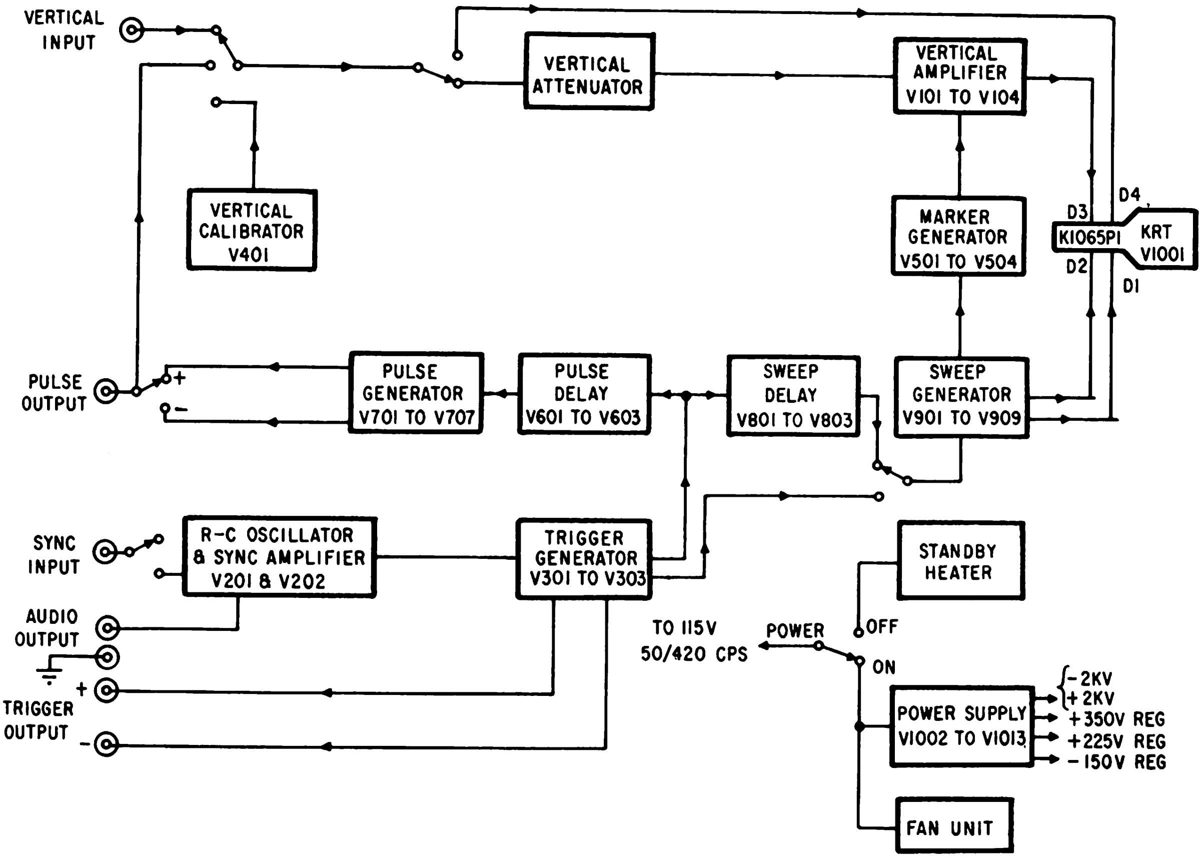


Figure 15-7.—Block diagram of pulse generator, SG-30/UPM.

of this function. Under this operating condition, electron flow to the collector structure is increased. The electron beam, therefore, diverges from its normal path. Comparatively few electrons are able to return to the cathode through the narrow opening on the collector structure due to a concentrated space charge and divergence of the electron beam. The field created near the cathode is virtually unaffected by the potential applied to the first grid.

Consider now that the first grid has been made positive with respect to the cathode. Under this condition the electron beam passes through the first grid and continues towards the plate electrode. As the electron beam emerges from the collector structure it is focused by the fields created by the collector structure, first grid, and second grid. If the potential on the second grid is sufficiently negative with respect to the cathode, the beam is reflected away from this grid and returns to the outside surface of the collector structure. (See fig. 15-9 (B) and (D)). If the second grid is made positive with respect to the cathode, part of the electron beam continues to the plate electrode.

As shown in figure 15-9 some collector current flows at all times. When either of the control grids is made more negative, with respect to the cathode, than cutoff, the current which would otherwise flow to the plate goes to the collector and, therefore, increases the collector current. The point at which this electron flow changes direction is extremely sharp. This results in a fast switching action between the plate and collector circuits. The cathode current remains constant under all grid bias conditions. This type of tube operation is utilized in the shaper circuit, V301 of the trigger generator. (See fig. 15-8.)

A bias of approximately -8.0 volts is applied to the first grid of V301. The second grid is supplied with a potential of approximately 65 volts. With these voltages applied to the grids, no plate current flows in the circuit. The RC

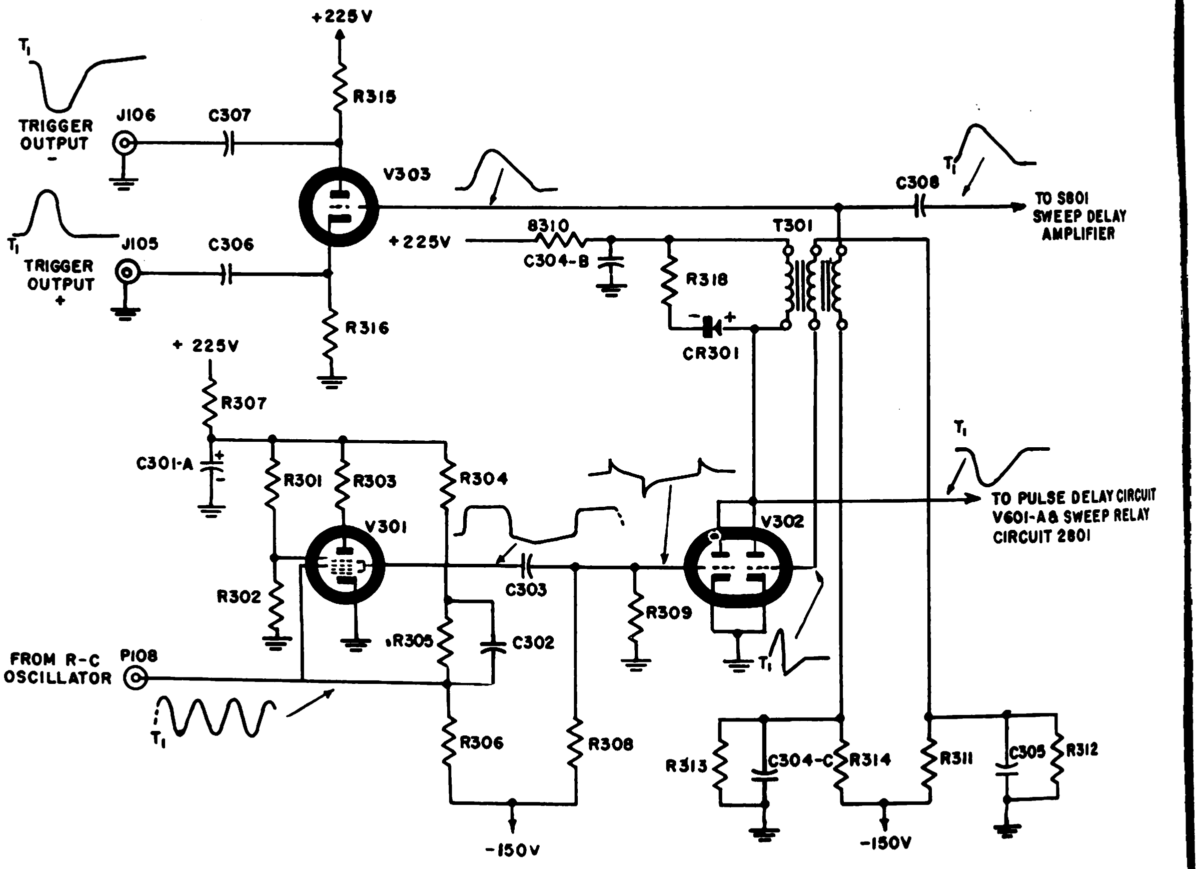


Figure 15-8.—Trigger generator, simplified schematic.

oscillator's output is applied to the first grid. Assuming that this is a sine wave, on the positive half cycle the first grid is driven less negative, causing electron flow to the plate. This results in reduced collector current and a lower voltage drop across R304. C302 couples this rise in voltage to the grid, which results in a further increase in plate current. This action is cumulative, resulting in a rapid regenerative action until the collector current is drastically reduced and maximum plate current results.

During the negative cycle of the sine wave, the electrons are reflected to the collector, thus increasing the collector current with a resulting low plate current. The output waveform is a representation of the instantaneous voltage variations at the collector. As a result of this rapid switching action between the plate and the collector, the sine wave output from the RC oscillator is converted to square waves. The square wave output from the shaper is coupled to the driven blocking oscillator through a short time constant RC circuit consisting of C303 and R309.

Pulse Generator

The pulse generator is essentially a basic one-shot multivibrator whose conduction time is varied by means of a front panel control. The pulse generator is preceded by a pulse delay circuit which enables the operator to adjust the time at which the pulse is generated relative to the trigger pulse. Pulses of either positive or negative polarity are coupled to a front panel terminal.

Display and Measuring Circuits

The cathode-ray tube ia a three-inch DuMont type K1065P1. It is characterized by its short

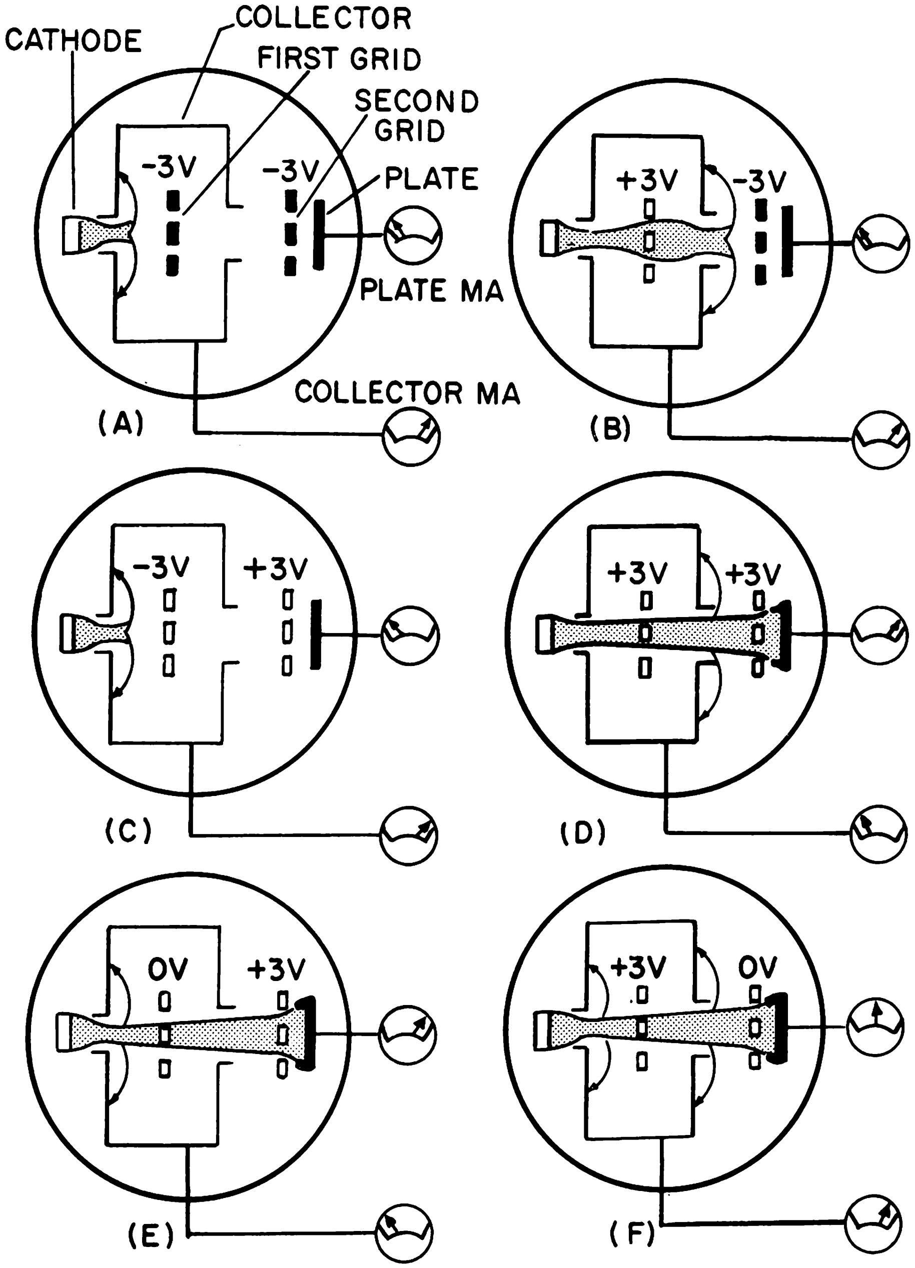


Figure 15-9.—Beam distribution system for 6BN6.

physical length, flat face, high-light output, and high sensitivity. The tube is provided with a shield cover and a transparent, plastic screen graduated in inches and tenths of inches.

The sweep generating circuit furnishes deflection voltages to the cathode-ray tube for producing the horizontal sweep. This circuit consists basically of a triggered multivibrator gate generator, a sweep forming circuit, a sweep inverter-amplifier, sweep clamping circuits, and a pulse disabling circuit. The designs are conventional with the exception of the trigger disabling circuit, which is designed to provide for stable operation of the sweeps for long durations and at high repetition rates. A simplified schematic of the sweep gate generator is shown

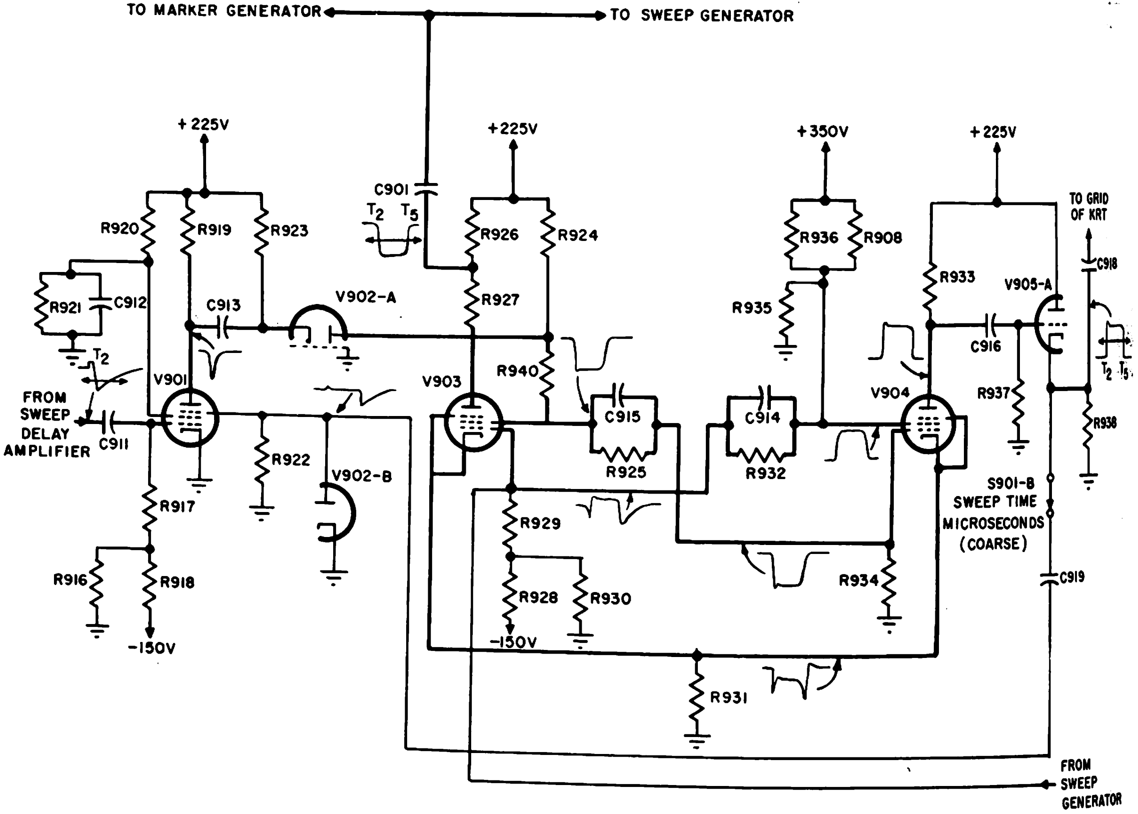
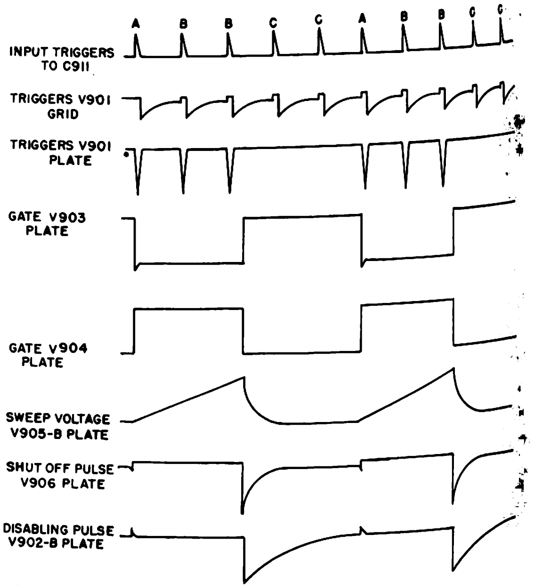


Figure 15-10. —Sweep gate generator.

in figure 15-10. Referring to this schematic, note that positive triggering pulses from the sweep delay circuit are applied to the control grid of V901, the trigger disabler. Assuming the suppressor grid to be at zero potential with respect to the cathode, the tube will conduct heavily, producing negative-going pulses in the plate circuit. If the suppressor is negative with respect to the cathode, current cannot flow even through the control grid is driven positive by the triggering pulses. It is this characteristic of V901 which is utilized to provide trigger disabling.

A negative pip is generated by differentiating the trailing edge of the unblanking gate. This pip corresponds in time to the retrace interval of the sawtooth sweep signal, as shown in figure 15-11. This pip is applied to the suppressor grid of V901. The negative signal holds V901 in a nonconducting state for the full flyback time of the sweep, preventing triggering of the sweep-gate generator during this period. Since the flyback time varies with the duration of the sweep, the capacitor in the differentiating network is switched by the SWEEP TIME MICROSECONDS



NOTES:
A SELECTED TRIGGER INITIATES SWEEP GATE MULTIVIBRATOR
B TRIGGER REJECTED BECAUSE OF DISCONNECTING EFFECT OF TRIGGER COUPLING DIODE V902-A
C TRIGGER REJECTED BECAUSE OF DISABLING PULSE FROM V902-B PLATE

Figure 15-11. —Waveforms, sweep generator.

COARSE, to insure that the time constant is always long enough to hold V901 for the required time.

SWEEP TIME CALIBRATION

The marker generator is basically a gated Hartley oscillator, followed by amplifier and wave shaping stages. The marker generator furnishes accurate timing pulses of 0.2, 1, 5, or 25 microsecond spacings. These pulses in the form of pips enable the operator to calibrate the sweep trace and measure unknown characteristics of the input signal. The marker generator output can be superimposed on the vertical input signal, or viewed separately. The generator is keyed by a negative gate pulse from the sweep-gate generator. This accomplishes automatic synchronization with the sweep at all times.

VERTICAL AMPLIFIER

The vertical amplifier is preceded by a vertical attenuator circuit providing various voltage ratios for its output signal. By means of a front panel switch, three signals of different origin may be applied to the vertical attenuator and amplifier. These are (1) a vertical amplitude calibration signal, (2) an internally generated pulse signal, and (3) an external signal.

To obtain the vertical amplitude calibration signal a ripple output from the low voltage power supply is capacity coupled to a divider network. This network is composed of a current-limiting resistor in series with a parallel circuit of a clamper, a limiter, and a variable resistor (fig. 15-12). The cathode of the clamper is connected directly to ground, which prevents any positive excursions of the voltage. A regulated -150 volts is applied to the plate of the limiter. With this combined clamping and clipping action, a square-wave signal of 150 volts peak-to-peak is produced across the AMPLITUDE-CALIBRATION POTENTIOMETER. The potentiometer is adjusted for 50 volts peak-to-peak across a divider network, furnishing calibration voltages of 0.5, 5, and 50 volts.

The internally generated pulse signal may be a negative or a positive pulse from the pulse generator. An external signal may be connected either to the vertical attenuator and amplifier or directly coupled to the vertical deflection plate on the cathode-ray tube.

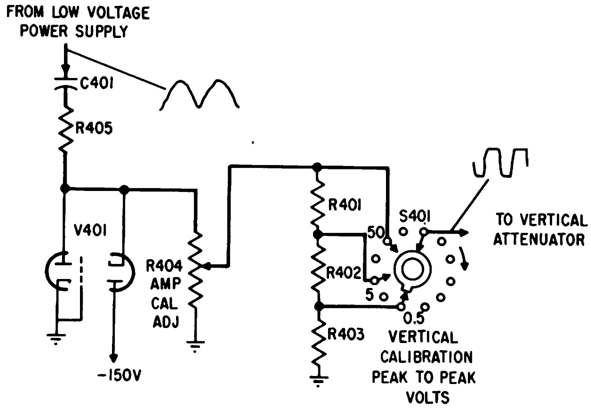


Figure 15-12. —Vertical amplitude calibrator simplified schematic.

Power Supply

The power supply furnishes all operating voltages for the equipment when supplied with 103.5 to 126.5 volts, 50 to 420 c.p.s. Regulated voltage outputs have been supplied to all critical circuits to improve stability and overall performance. The three low-voltage power supplies are conventional half-wave and full-wave rectifiers electronically regulated. The high-voltage power supply consists of two separate half-wave, RC filtered, rectifier circuits. One provides the cathode-ray tube intensifier anode with a positive potential of 2,050 volts. The other provides approximately a negative 1,950 volts across a voltage divider. From the various taps on this network proper operating potentials are obtained for correct focusing of the cathode-ray beam.

RADAR TEST SET AN/UPM-32

Radar Test Set An/UPM-32 is a portable test set designed primarily for use with radar sets operating in the frequency range of 8,500 to 10,500 mc. It combines in one test set all the functions of a power meter, a frequency meter, a spectrum analyzer, a signal generator, and a general-purpose synchroscope. Figure 15-13 illustrates the AN/UPM-32, indicating all of its front panel controls.

The general applications of the test set are as follows:

1. Measurement of power, frequency, spectrum, and frequency pulling of conventional and multipulsed radar transmitters.

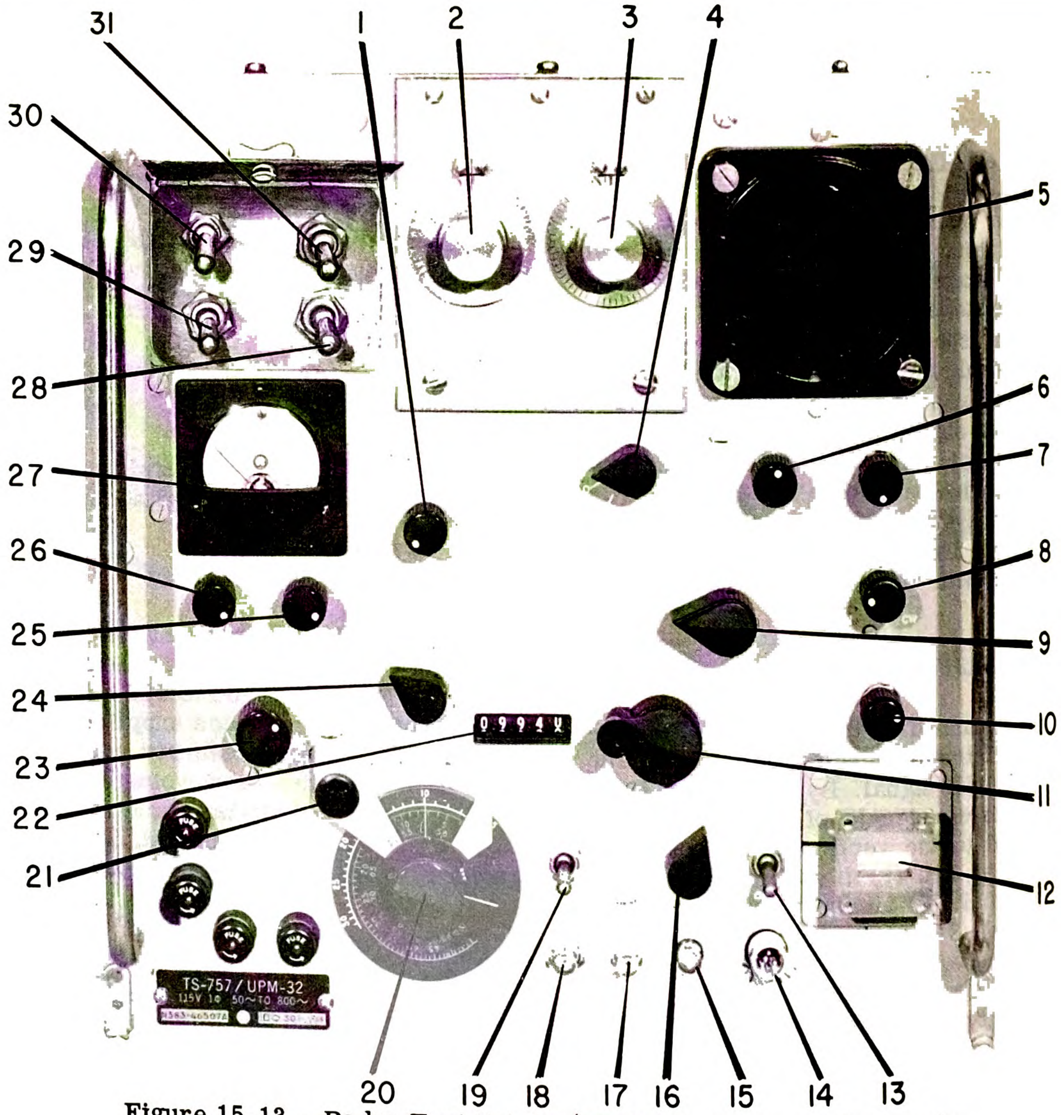


Figure 15-13.—Radar Test Set AN/UPM-32, front panel controls.

1. POWER SET control.
2. PULSE OR GATE WIDTH control.
3. DELAY MULTIPLIER control.
4. DELAY and SWEEP LENGTH switch.
5. Cathode-ray tube.
6. VERT CENTER control.
7. SIGNAL GAIN control.
8. SIGNAL WIDTH control.
9. Function selector switch.
10. SPECTRUM SWEEP FREQUENCY control.
11. Frequency control.
12. RF connection.
13. ON-OFF switch.
14. 115 VAC connector.
15. SIGNAL connector.
16. SIGNAL switch.
17. TRIGGER IN connector.
18. EXT MOD connector.
19. TRIGGER switch.
20. DBM control.
21. Indicator light.
22. FREQUENCY counter.
23. OSC FREQUENCY control.
24. ATTENUATION switch.
25. REFLECTOR control.
26. METER BALANCE control.
27. Power meter.
28. ASTIG control.
29. MODE GAIN control.
30. FOCUS control.
31. INTENSITY control.

2. Measurement of sensitivity and bandwidth of a radar receiver.
3. Measurement of the frequency and spectrum of a radar-receiver local oscillator.
4. Adjustment of a radar-receiver local oscillator.
5. Measurement of TR recovery time.
6. Observation of video signals.
7. Furnishing pulsed, FM or CW microwave signals.

From the preceding list of applications it should be obvious that the AN/UPM-32 is a very versatile test set and may be used in place of the FM Test Set (TS-147) and Spectrum Analyzer (TS-148) which have, in the past, had widespread usage throughout the fleet in radar testing, troubleshooting, and alinement.

Operating Controls and Indicators

Table 15-2 lists the operating controls and indicators used in operation of the AN/UPM-32. Column 1 of the table lists the control; column 2 lists the number as illustrated in figure 15-13; and column 3 lists the functions of the control indicated.

Table 15-2.—Operating controls and indicators of AN/UPM-32 (fig. 15-13).

Control	Number	Function
115 VAC connection	14	Provides connection for line power to test set.
ON-OFF switch------	13	OFF position: Deenergizes circuits.
		ON position: Energizes circuits.
ATTENUATION switch--	24	HI position: Sets range of DBM control to HI scale.
		LO position: Sets range of DBM control to LO scale.
DBM control--------	20	Adjusts attenuation of input or output microwave signals. Calibrated in dbm.
Function selector switch.	9	MIXER position: Enables observation of mode pattern of test set klystron oscillator.
		NORMAL position: Enables observation of frequency spectrum of external RF pulse.
		GATED position: Enables observation of frequency spectrum of single external RF pulse from a multipulsed radar system.
		GATE ADJ position: Enables selection of a single pulse from a pulse train for preceding GATED position.
		PWR-FREQ METER position: Enables measurement of power and frequency of external RF signals. Also enables use of test set as synchroscope.
		PULSE MOD position: Enables operation as an RF pulse-modulated signal generator.
		FREQ MOD position: Enables operation as an RF frequency-modulated signal generator.
		EXT MOD position: Enables operation as an RF signal generator whose modulation is determined by an external signal. If no external modulation is applied, the test set operates as a CW signal generator.
RF connection---	12	Provides connection for incoming or outgoing RF signals.
METER BALANCE control.	26	Zeros power meter.

Table 15-2.–Operating controls and indicators of AN/UPM-32 (fig. 15-13)–Continued.

Control	Number	Function
Power meter--	27	Monitors standard power reference level (one milliwatt).
FREQUENCY counter.	22	Indicates resonant frequency (in megacycles) to which frequency-meter cavity is tuned.
Frequency control.	11	Changes resonant frequency of meter cavity
SIGNAL WIDTH control.	8	MIN position: Minimum pattern width on cathode-ray tube.
		CW position: Maximum pattern width on cathode-ray tube.
POWER SET control.	1	Sets output power of test set klystron oscillator. Maximum power is obtained with control set fully clockwise.
SIGNAL GAIN control.	7	Sets vertical deflection sensitivity of cathode-ray tube.
REFLECTOR control.	25	Function Selector switch in MIXER position. Shifts klystron oscillator mode horizontally on cathode-ray tube.
		Function Selector switch in NORMAL or GATED positions: Shifts spectrum pattern horizontally on cathode-ray tube.
		Function Selector switch in FREQ MOD position: Shifts radar receiver band-pass curve horizontally on cathode-ray tube.
		Function Selector switch in EXT MOD position: Adjusts klystron oscillator for maximum power output at a particular frequency.
VERT CENTER control.	6	Sets the vertical position of the trace on the cathode-ray tube.
OSC FREQUENCY control.	23	Sets output frequency of test set klystron oscillator.
TRIGGER IN connector.	17	Provides connection for incoming video triggers.
TRIGGER switch..	19	RF position: Connects detected signal, from RF Connection, to sweep and pulse-generator circuits.
		EXT position: Connects external video pulse, applied to TRIGGER IN connector, to sweep and pulse-generator circuits.
Cathode-ray tube.	5	Presents (visually) output signals from test set IF amplifier, video amplifier, RF mixer, and gating circuit.
SIGNAL connector.	15	Provides connection for incoming video signals.
SIGNAL switch.	16	INT position: Connects output of RF mixer to video amplifiers.
		X1, X10, or X100 positions: Connects external video signals, applied to SIGNAL connector, to video amplifiers. The signals are attenuated by 0, 10 to 1, and 100 to 1, respectively.

Table 15-2.—Operating controls and indicators of AN/UPM-32 (fig. 15-13)—Continued.

Control	Number	Function
DELAY and SWEEP LENGTH switch.	4	Function Selector switch in GATE ADJ, PWR-FREQ METER, PULSE MOD, FREQ MOD, and EXT MOD positions: Sets sweep length on cathode-ray tube. In addition, with the Function Selector switch in GATED and GATE ADJ positions: Sets gate delay in conjunction with DELAY MULTIPLIER control; and with the function selector switch in PULSE MOD position: Sets pulse delay in conjunction with DELAY MULTIPLIER control.
DELAY MULTIPLIER control.	3	Function selector switch in GATED, GATE ADJ, or PULSE MOD positions: Multiplies gate or pulse-delay setting on DELAY and SWEEP LENGTH switch.
SPECTRUM SWEEP FREQUENCY control.	10	Function selector switch in NORMAL or GATED positions: Sets frequency of spectrum sweep generator for best spectrum pattern on cathode-ray tube.
PULSE OR GATE WIDTH control.	2	Function selector switch in GATED or GATE ADJ positions: Varies width of gating pulse. Function selector switch in PULSE MOD position: Varies width of modulating pulse.
EXT MOD connector.	18	Function selector switch in EXT MOD position: Provides connection for external modulating signals.

General Description

Through the use of the master function selector switch, (number 9, fig. 15-13), the internal circuits may be switched into the desired operation to perform any of the functions previously mentioned.

POWER-METER OPERATION

When it is desired to use the test set as a power meter, input signals from a radar transmitter pass through a calibrated variable attenuator to a temperature-compensated power monitor illustrated in figure 15-14 in block form. The power monitor is comprised of a bridge circuit and a power-level indicating meter calibrated in milliwatts and dbm (decibels relative to one milliwatt).

FREQUENCY-METER OPERATION

When the frequency-meter function of the test set is used, an absorption-type frequency meter is tuned to resonance. (See fig. 15-14.) The resonant frequency-meter cavity causes a reduction of the power level in the microwave section at the frequency to which the cavity is

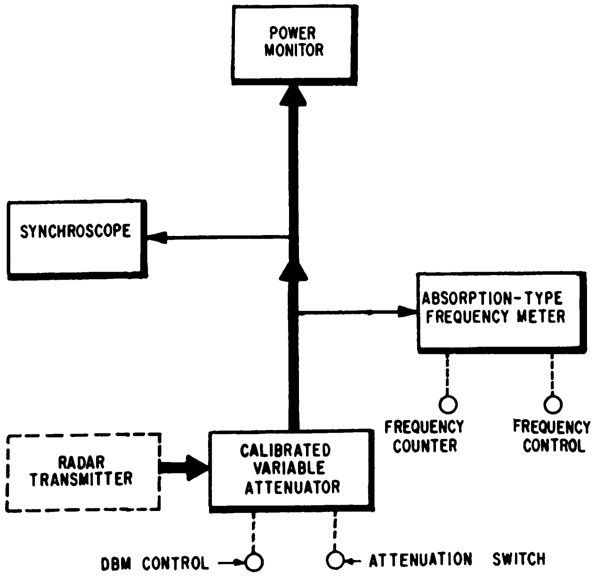


Figure 15-14.—Power-meter and frequency-meter operation, simplified block diagram.

tuned. This reduction of power, at the resonant frequency, appears as a dip on the power-monitor meter or on the screen of the synchroscope. The resonant frequency (in megacycles) is indicated directly on a front panel counter (number 22, fig. 15-13,) which is geared mechanically to the tuning mechanism of the cavity. The power-meter frequency-meter operation of the AN/UPM-32 closely resembles the construction and operation of the TS-147 frequency-meter test set. Therefore, with an understanding of this portion of the AN/UPM-32, the technician should have little trouble in the operation and use of the TS-147 if the AN/UPM-32 is not available.

SPECTRUM-ANALYZER OPERATION

For the spectrum-analyzer function, the test set's klystron oscillator is frequency modulated by the sawtooth output of a sweep generator. (See fig. 15-15.)

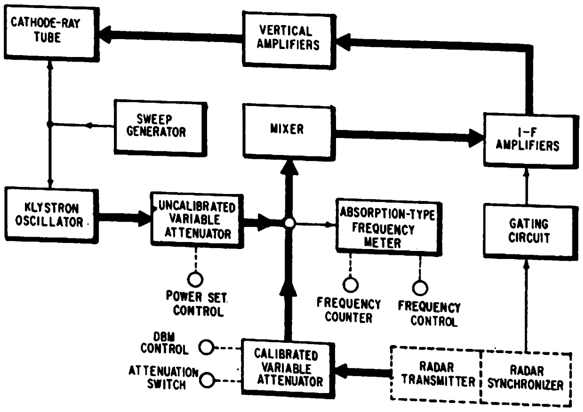


Figure 15-15.—Spectrum-analyzer operation, simplified block diagram.

The radar-transmitter signal to be observed and the klystron-oscillator signal are combined in a mixer to produce heterodyne frequencies which are fed to an IF amplifier. For each radar-transmitter pulse, a frequency component of the pulse beats with the klystron-oscillator signal to produce a 45-mc. IF signal. For successive radar-transmitter pulses, a different frequency component causes the 45-mc. beat frequency to appear because the klystron oscillator is frequency modulated. The detected IF signals are amplified and applied to a cathode-ray tube. Since the horizontal-deflection system of the cathode-ray tube is driven by the same sawtooth used for klystron modulation, the CRT pattern is a plot of frequency versus power for the input signal.

The test set also includes a gating circuit which permits the observation of the spectrum of any pulse in the output of a multipulsed radar transmitter. For this operation, the radar synchronizer is used to feed a pretrigger to the test set gating circuit to avoid triggering on the wrong RF pulse. This circuit, in turn, generates a pulse which gates the IF amplifier so that any signals applied during the gating period pass through the amplifier. The gating period is long enough to permit only the frequency samples from one radar-transmitter pulse to pass through the IF amplifier. The gating pulse may be delayed relative to the pretrigger for the desired pulse selection.

This portion of the AN/UPM-32 closely resembles the operation of the Spectrum Analyzer TS-148 with the exception of the gating circuit function used for testing multipulsed radar transmitters. (NOTE: The Spectrum Analyzer is discussed in *Basic Electronics*, NavPers 10087.) This feature is not available with the TS-148. However, with an understanding of the AN/UPM-32 spectrum-analyzer operation, the technician will have little trouble understanding and operating the TS-148 for spectrum analyzation if the AN/UPM-32 is not available.

SIGNAL-GENERATOR OPERATION

When the test set is used as a signal generator, it supplies FM, pulse-modulated, externally modulated, or CW microwave signals. This portion of the AN/UPM-32 is illustrated in block form in figure 15-16.

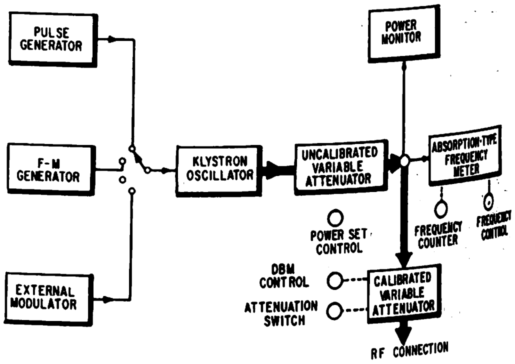


Figure 15-16.—Signal-generator operation, simplified block diagram.

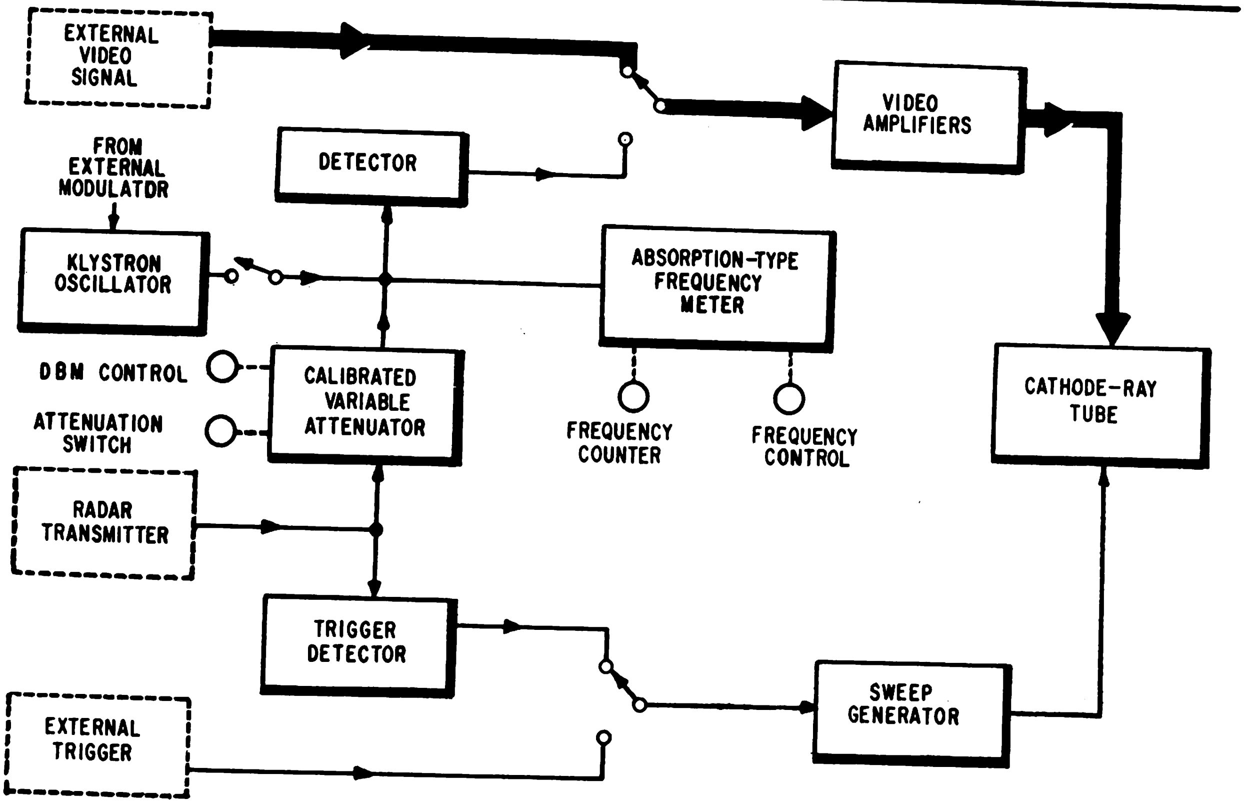


Figure 15-17.—Synchroscope operation, simplified block diagram.

For the FM and pulse-modulated signals,' nternal circuits provide the modulating waveorms, but a trigger must be provided by an xternal source. Any desired type of modulation aveform can be applied to the klystron oscillaor, and the test set will provide correspondingly odulated RF signals. The power level and freuency of all output signals are adjustable to the sired level within the limits of the test set.

NCHROSCOPE OPERATION

When the test set is operated as a generalrpose synchroscope, a video signal is applied the video amplifiers. The amplified signal applied to the vertical-deflection circuit of cathode-ray tube as illustrated in block m in figure 15-17.

This video signal can be externally applied, it may be an internal signal taken from the xer crystal (detector). The sweep generator, ich drives the horizontal-deflection system the cathode-ray tube, must be triggered and chronized with the video signal, either by an external trigger source associated with the video signal or by the detected RF pulse from the radar transmitter.

Functional Operation

MICROWAVE ASSEMBLY

The microwave assembly makes possible the measurement of the power level and frequency of input and output signals. The assembly consists basically of a block containing waveguides and attenuating sections. Within the assembly both the klystron signal and RF input signals are mixed to obtain a spectrum pattern. Signal flow in the assembly depends upon the setting of the function selector switch to the desired mode of operation (number 9, fig. 15-13).

With the function selector switch on MIXER position, energy flow in the assembly is illustrated in figure 15-18. The power set attenuator adjusts the power level of the klystron signal. Because the klystron oscillator is sawtooth

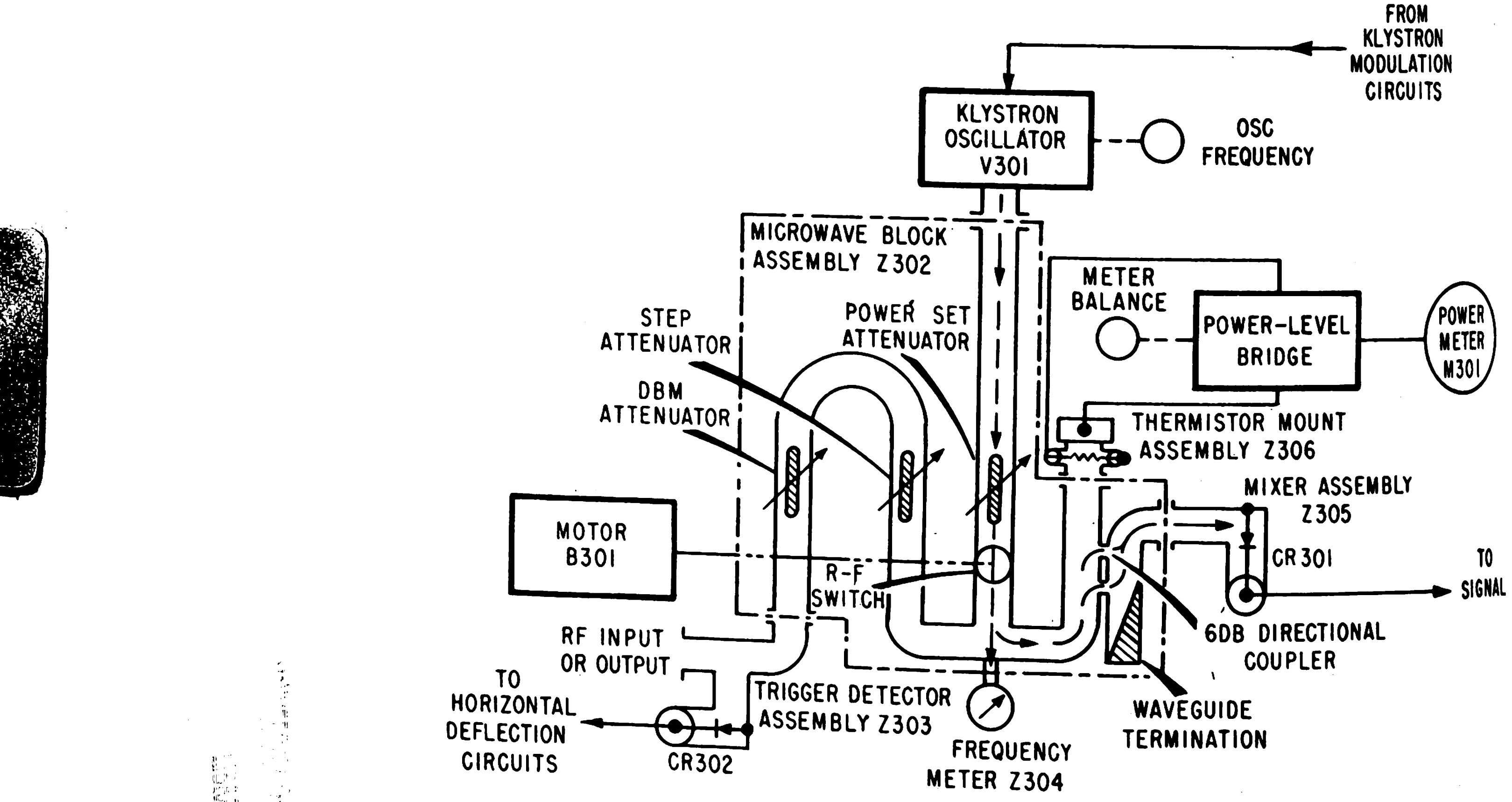


Figure 15-18.—Energy flow in microwave assembly, function selector switch at MIXER.

modulated by the sweep generator circuits (fig. 15-15), its output frequency varies linearly during the sawtooth excursion. Therefore, if the frequency meter is tuned to a frequency within the range covered by the klystron output, a sharp reduction in power level occurs at this particular frequency. This reduction appears as a dip in the pattern displayed on the CRT indicator. The frequency of the klystron may then be read directly, in megacycles, from the frequency meter Z304.

With the function selector switch in the NORMAL or GATED position, two signals are present in the microwave assembly. (See fig. 15-19.) The klystron signal and the transmitter signal are mixed in the mixer crystal which produces heterodyne frequencies. The 45-mc. component appearing during each radar output pulse passes through a tuned filter network to the IF amplifier stages. Because of the linear sawtooth modulation applied to the klystron, the klystron signal beats with a different frequency component of the radar output during each transmitted pulse interval to produce this 45-mc. beat frequency. Hence, the amplitude of each 45-mc. pulse is a measure of the power contained in the particular magnetron frequency component producing it. The magnetron spectrum is thus produced and appears on the CRT indicator. The importance of this presentation lies in the fact that with it a radar transmitter can be tuned to give a spectrum in which the greatest possible portion of the high-power frequency components falls within the bandpass of the radar receiver.

When the function selector switch is placed in the PWR-FREQ. METER position, the radar-transmitter power is fed through the microwave assembly as shown in figure 15-20. The RF switch is closed, hence there is no power division at the tee (T) junction nor can any klystron power reach the thermistor mount. This permits measurement of the power level of the incoming signal. The step attenuator should be at its minimum (LO) position.

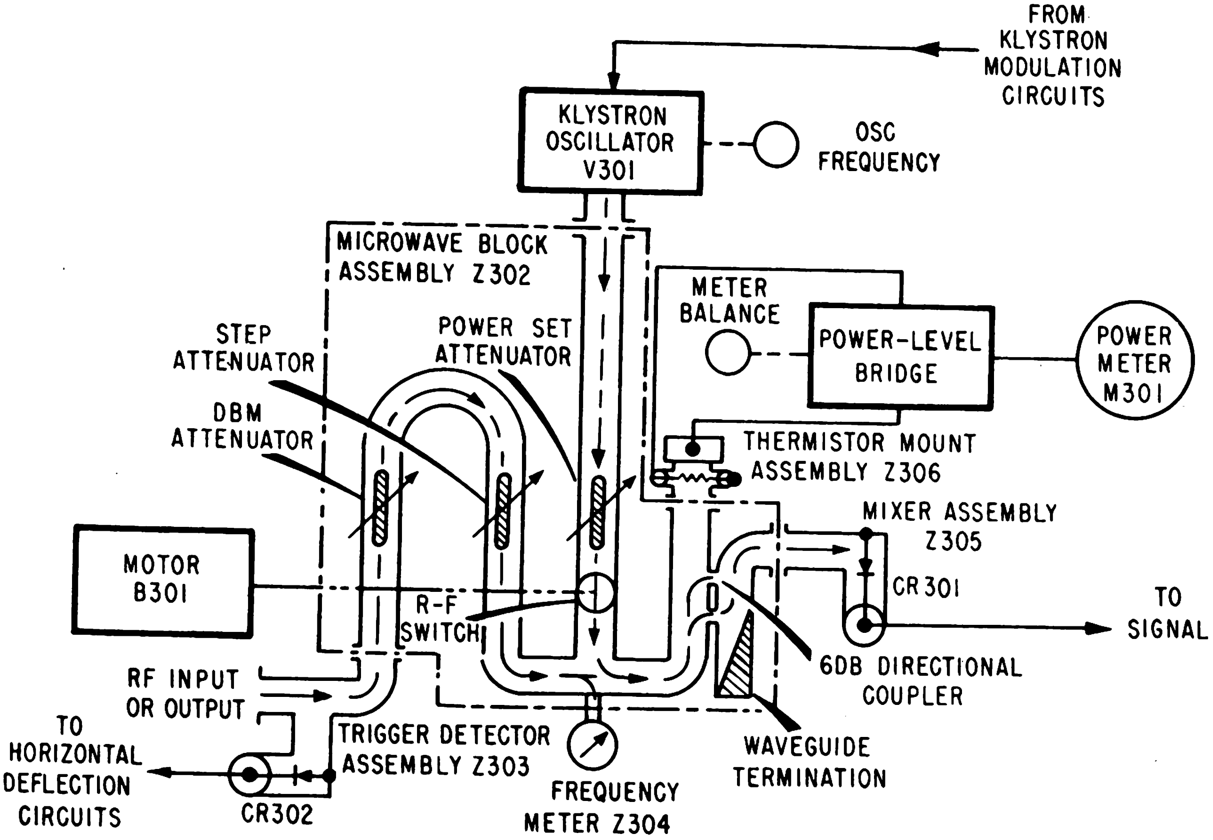


Figure 15-19.—Energy flow in microwave assembly, function selector switch at NORMAL/OR GATED.

For the PULSE MOD, FREQ MOD, and EXT MOD positions of the function selector switch, signal flow is shown in figure 15-21. The power level of the klystron RF signal is set by the power set attenuator. The frequency of the signal is indicated by the frequency meter which is used in conjunction with either the power-level indicating meter or the synchroscope pattern on the CRT. Since there is an equal division of power in the tee (T) junction following the RF switch, the reading of the power-level bridge meter, as modified by the DBM attenuator dial reading, gives an accurate indication of the power level of the test set output signal. The signal reaching the mixer crystal is detected, and the signal, which is the modulation waveform, can be viewed on the CRT by setting the signal switch at INT if desired (number 16, fig. 15-13).

TRIGGER-DETECTOR ASSEMBLY

The trigger-detector assembly (Z_{303}, fig. 15-21) consists of a removable mount attached to the rectangular waveguide section at the input of the microwave assembly. The mount contains a crystal rectifier element (CR_{302}) and functions as a fixed-tuned detecting section. Isolation from the main waveguide is provided by an iris which attenuates the energy from the main waveguide about 35 db to protect the crystal from burnout.

DBM ATTENUATOR

The DBM attenuator consists of a rectangular glass vane coated with a resistive material. The vane is mounted inside the waveguide parallel

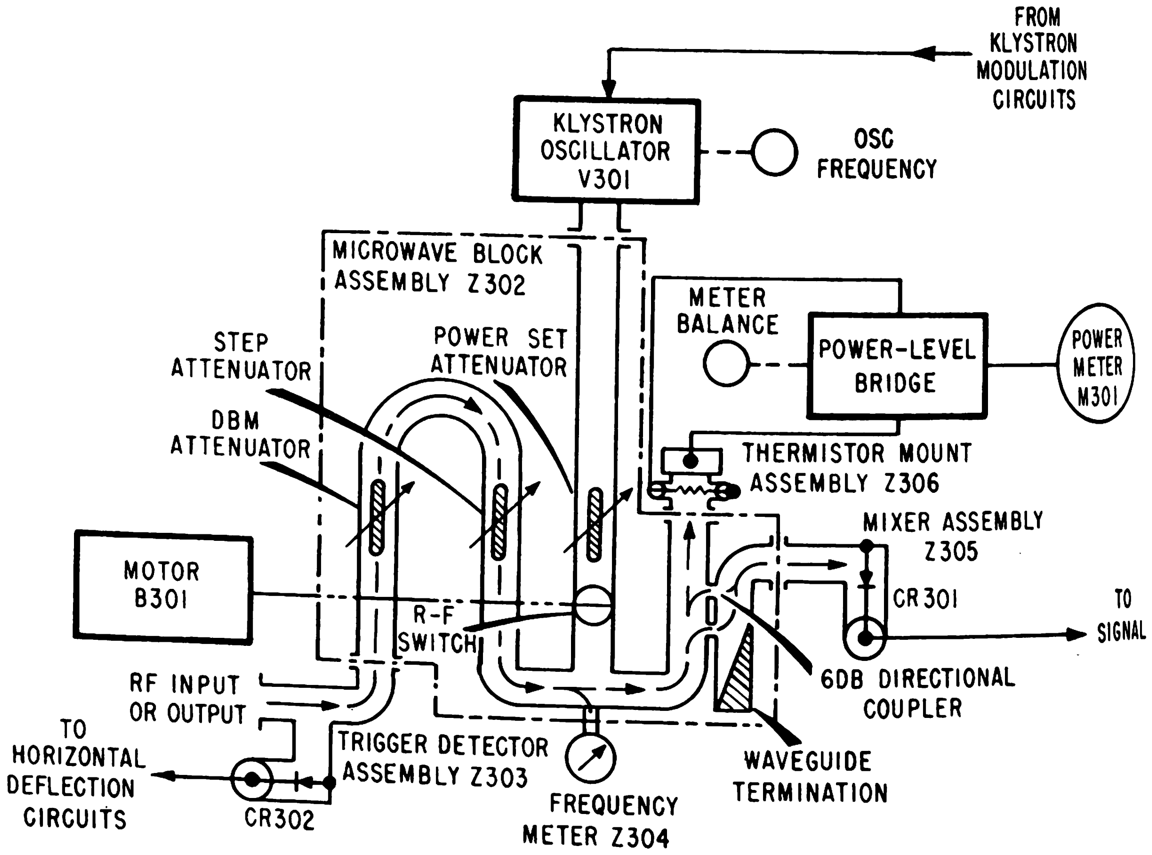


Figure 15-20. —Energy flow in microwave assembly, function selector switch at PWR-FREQ METER.

to the narrow wall, and its position is continuously adjustable (by the DBM control, number 20, fig. 15-13) from the narrow wall toward the center of the waveguide. The maximum attenuation introduced by the vane (near the center) is approximately 50 db. The calibration of the DBM dial accounts for this attenuation and the known losses in the microwave block.

STEP ATTENUATOR

The step attenuator is constructed in the same fashion as the DBM attenuator. The step attenuator is controlled by the ATTENUATION switch (number 24, fig. 15-13) which has two settings, HI and LO. In the HI position, the vane is near the waveguide center; and in the LO position, it is adjacent to the narrow wall. For the HI position of the switch, the step attenuator introduces about 50 db of attenuation in the waveguide run.

RF SWITCH

The RF switch consists of a cylindrical element which closes off the waveguide leading to the klystron when the function selector switch is on the PWR-FREQ METER position. The axis of the switching device is parallel to the broad walls of the waveguide. The device has a rectangular hole through it, which lines up with the waveguide for the open position and rotates through a quarter turn to close off the waveguide run to the klystron. A metallic window which projects part way across the guide opening inside the device serves as an impedance matching device for the waveguide tee (T).

RF OSCILLATOR

The microwave oscillator tube (V301) used in the test set is a reflex klystron which operates on the principle of velocity modulation. The

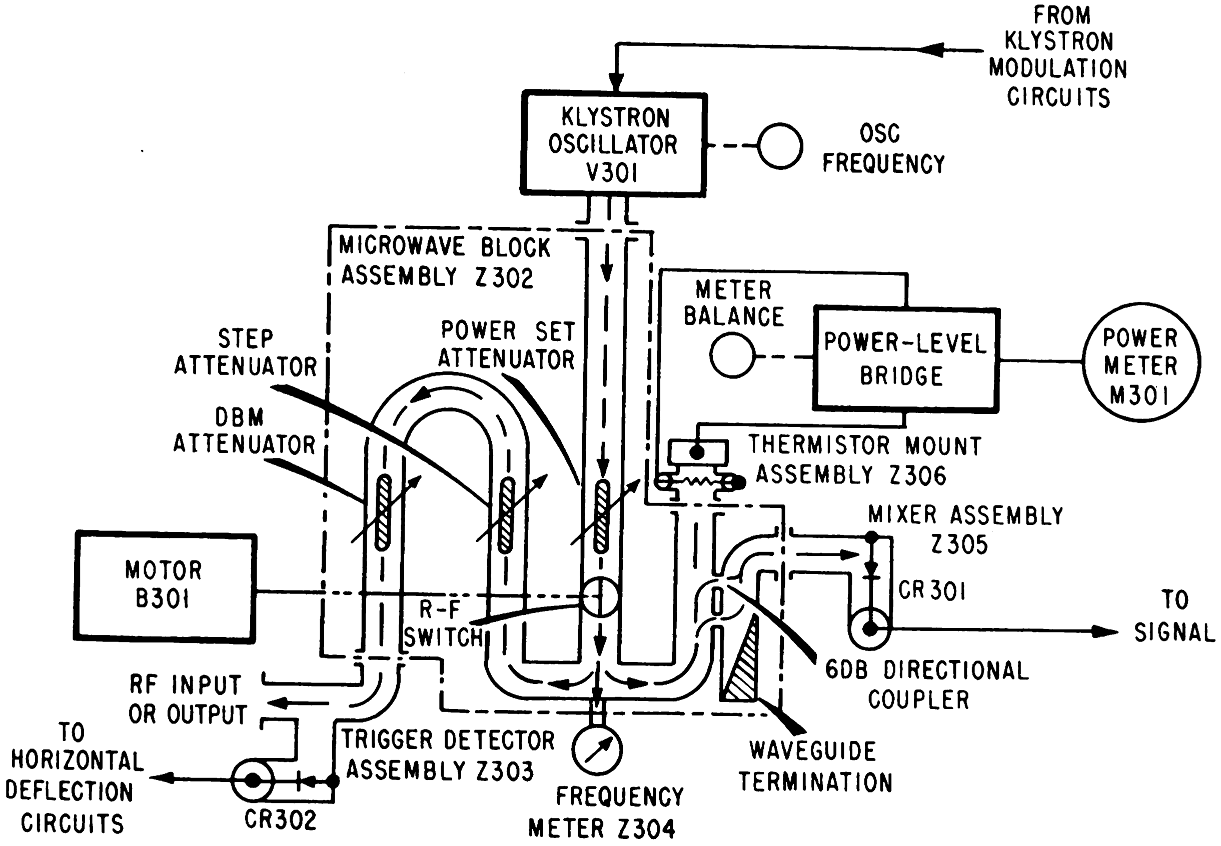


Figure 15-21.—Energy flow in microwave assembly, function selector switch at PULSE MOD, FREQ MOD, OR EXT MOD.

lystron may be tuned either mechanically by arying the volume of the resonator cavity or lectrically by varying the reflector (repeller) late voltage. Mechanical tuning is accomplished rom the top of the klystron by the OSC FRE-UENCY control (number 23, fig. 15-13). Elec-rical tuning, is accomplished by the modulation awtooth from the modulation sweep generator rcuits and by the reflector control (number 5, fig. 15-13). NOTE: A detailed discussion on e construction and operation of the reflex ystron was given in chapter 7 of this course.)

OWER SET ATTENUATOR

The power set attenuator consists of a small ctangular glass vane coated with a resistive aterial. The adjustment of the vane position thin the waveguide is continuous, but the as-mbly is not calibrated. For the maximum enuation position near the waveguide center, attenuator decreases the level of the klystron tput signal by 20 to 25 db.

FREQUENCY METER

The frequency meter (Z_{304}) consists of a circular high-Q cavity with a movable concentric tuning plunger. The frequency meter is fitted into the microwave assembly and coupled to the waveguide by means of a circular iris, and the entire assembly is hermetically sealed. The tuning plunger mechanism is geared to the frequency counter which indicates the resonant frequency of the cavity in megacycles.

THERMISTOR-MOUNT ASSEMBLY

The thermistor-mount assembly (Z_{306}) is comprised of a short waveguide section terminated in a housing which contains a thermistor bead. The bead is sensitive to microwave energy, and its resistance changes in proportion to the level of energy in the waveguide. The assembly is mounted to the microwave section and fixed-tuned at the factory. A cylindrical subassembly is located on one side of the thermistor-mount assembly to hold a disk thermistor. This thermistor has a negative temperature coefficient of resistance. The resistance changes in the disk thermistor compensate the power-level bridge circuit for the effects that changes in the ambient temperature produce in the resistance of the thermistor bead.

MIXER ASSEMBLY

The mixer assembly (Z_{305}) is similar in construction to the trigger-detector assembly (Z_{303}), and it contains the same type crystal cartridge. When the function selector switch is on the MIXER, PWR-FREQ METER, GATE ADJ, PULSE MOD, EXT MOD, or FREQ MOD position, the mixer crystal acts as a simple RF detector. For operation in the NORMAL and GATED positions of the function selector switch, the radar-transmitter signal and the klystron signal are both present, and the putput of the mixer contains beat frequencies because of the nonlinear detection characteristic of the crystal. The mixer assembly also contains a 3-db isolation pad which is adjusted when installed and must not be disturbed by the field maintenance technician.

Electronic Circuits

The following discussion describes the electronic circuits of the test set. The circuits are grouped according to their particular functions. For coherence the circuit groups are described with reference to the simplified block diagram of figure 15-22. The actual circuit analysis by schematic diagrams is beyond the scope of this course. However, with an understanding of the general circuit description which follows, the technician should have little trouble in understanding the actual detailed circuitry analysis as described in the *Handbook of Service Instructions* for the equipment.

SIGNAL CIRCUITS

The signal circuits comprise the IF amplifier assembly, mode amplifier, vertical amplifier, video amplifiers, and the associated video input attenutators. For the MIXER position of the function selector switch, the frequency-modulated klystron-oscillator signal is detected by the crystal in the mixer assembly (located in the microwave block assembly) and fed through relay K_{402} to the filter circuit located in the IF

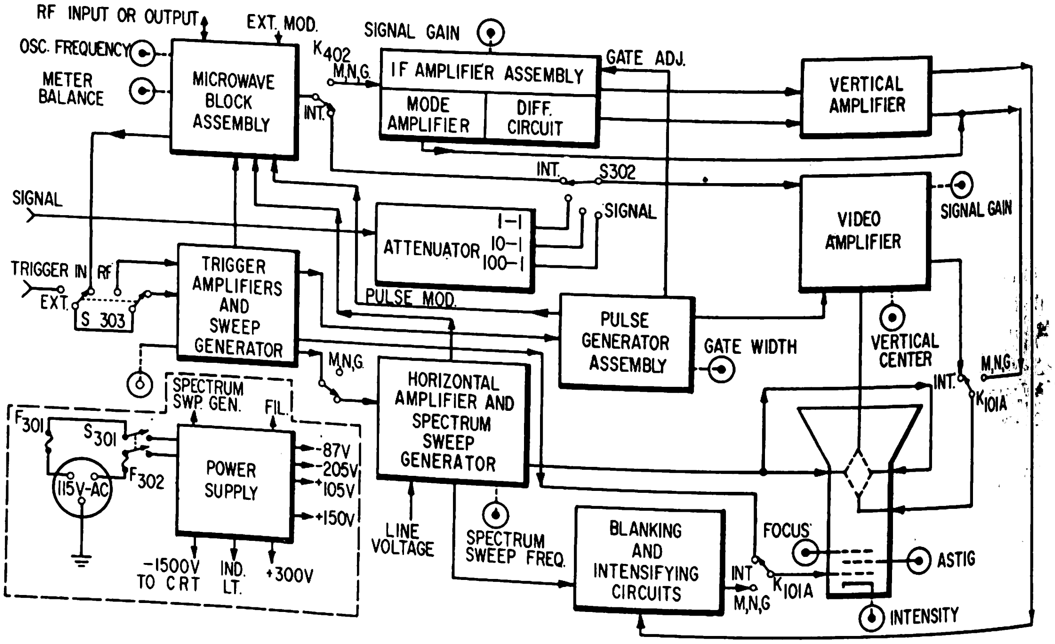


Figure 15-22.—Radar Test Set AN/UPM-32, simplified block diagram.

amplifier assembly. There being no 45-mc. component in the signal the output of the filter circuit consists of the envelope of the detected signal which is fed to the mode amplifier. The amplified signal (mode pattern) is then fed through relay K_{101A} to the vertical-deflection plates of the CRT.

For the NORMAL and GATED positions of the function selector switch, the output of the mixer crystal is applied to the filter circuit as before. If a radar transmitter signal is applied to the RF input, the resulting 45-mc. beat signal is amplified through the two 45-mc. IF amplifiers and mixed in the mixer (located in the IF amplifier assembly) with a 36.8 mc. local-oscillator signal produced by a mode oscillator. The resultant 8.2 mc. signal is amplified, detected, and applied to the vertical amplifier. The input to the vertical amplifier now consists of two signals—a differentiated output of the mode amplifier and the detected IF signal. The abrupt changes in the mode waveform, such as the beginning and the end of the curve and the pip caused by the frequency meter (if it is tuned to a frequency within the range swept by the klystron oscillator), are retained by the differentiation. Both the detected IF signal and the differentiated mode signal pass through the vertical amplifier and through relay K_{101A} to the vertical deflection plate of the cathode-ray tube. Figure 15-23

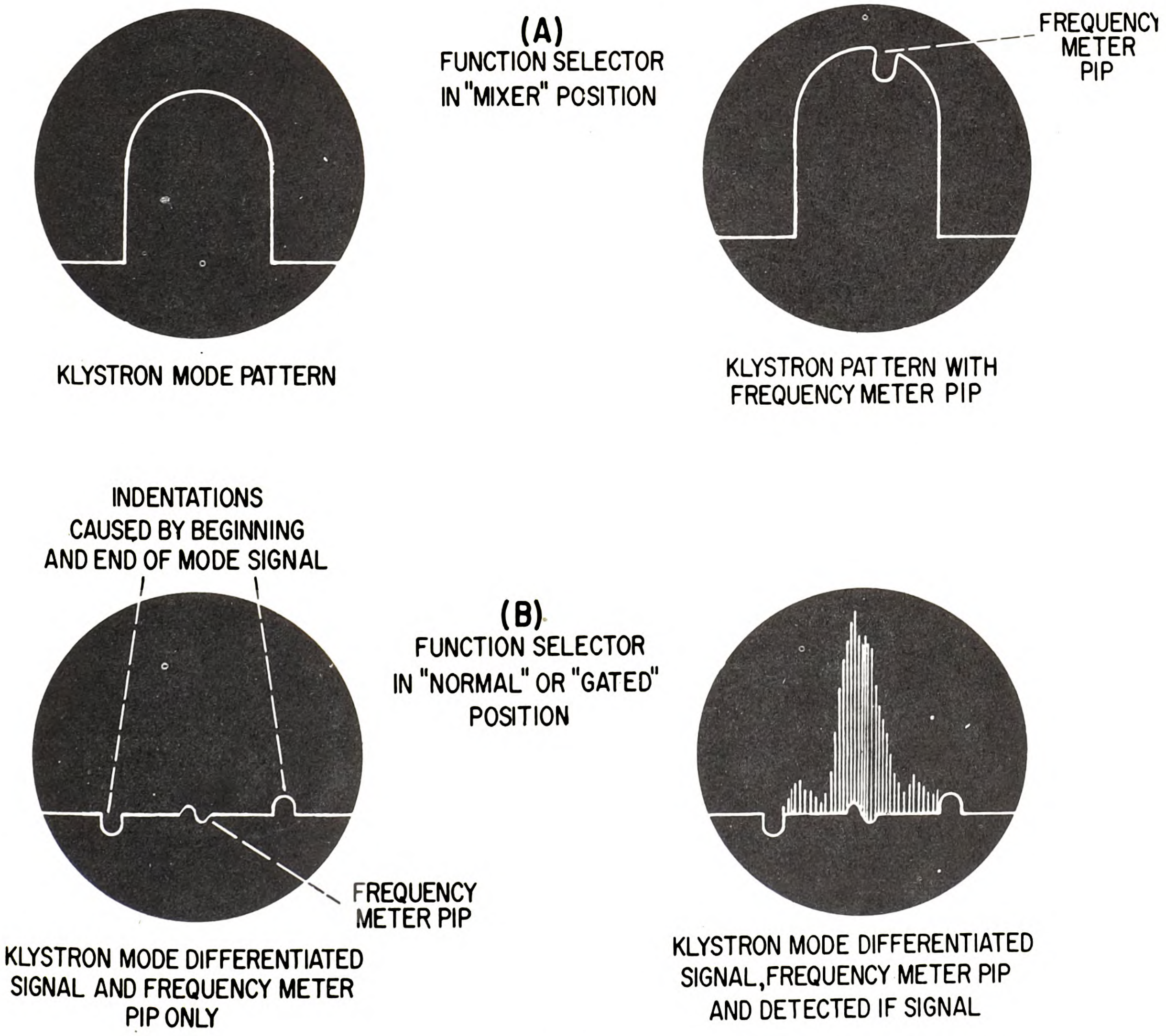


Figure 15-23.—Display patterns of the CRT. (A) MIXER position; (B) NORMAL or GATED position.

illustrates the pattern displayed on the CRT indicator with the function selector switch in the MIXER and NORMAL or GATED positions.

In the PWR-FREQ METER position of the function selector switch or in the PULSE MOD, FREQ MOD, or EXT MOD positions, either internal or external video signals can be applied to the video amplifiers for observation on the synchroscope. (See table 15-3.) The internal signal consists of the detected radar-transmitter pulse envelope which is taken from the mixer crystal and applied through relay K_{402}, and through signal switch S_{302} to the video amplifier. For the observation of an external video signal, connection is made to the signal connector and the signal switch thrown to EXT. Depending on the setting of signal switch S_{302}, the video signal is either fed directly or attenuated as desired before being applied to the video amplifier. The video amplifier stages drive the vertical-deflection circuit of the CRT for the synchroscope video display.

TRIGGER AMPLIFICATION AND HORIZONTAL DEFLECTION CIRCUITS

The trigger amplifier stage is used to amplify the input triggers which are used to synchronize the synchroscope sweep generator for the cathode-ray tube trace. The sweep generator may be triggered either externally or internally, depending on the position of the trigger switch S_{303} on EXT, the trigger may be taken from an outside source and applied to the trigger amplifier for starting the sweep generator. If on RF, the trigger originates at the trigger detector assembly, located in the microwave block assembly, and is fed through the trigger switch to the trigger amplifier for starting the sweep.

For the MIXER, NORMAL, and GATED positions of the function selector switch, the source of the horizontal-deflection voltage is the free-running spectrum sweep generator. The sweep generator is synchronized at line

Table 15-3.–AN/UPM-32 presentations.

Function	Signal switch position	Scope vertical presentation
MIXER	INT	Klystron RF envelope.
MIXER	EXT	Do.
NORMAL	INT	Spectra plus differentiated RF envelope.
NORMAL	EXT	Do.
GATED	INT	Gated spectra plus differentiated klystron RF envelope.
GATED	EXT	Do.
GATE ADJ.	INT	Envelope of RF input plus internal video gate.
GATE ADJ.	EXT	Internal video gate plus external video.
PWR-FREQ METER	INT	Envelope or RF input.
PWR-FREQ METER	EXT	External video.
PULSE MOD	INT	Envelope of RF input plus RF output.
PULSE MOD	EXT	External video.
FREQ MOD	INT	Envelope of RF input plus RF output.
FREQ MOD	EXT	External video.
EXT MOD	INT	Envelope of RF input plus RF output.
EXT MOD	EXT	External video.

NOTE: The frequency meter can cause a dip or reduction of power on any of the above internal or external RF derived waveforms if turned to the proper frequency.

frequency or subharmonics of it by an a-c voltage from the power supply. The output of the spectrum sweep generator (a sawtooth voltage) is fed to the horizontal amplifier. The horizontal amplifier drives the horizontal plates of the cathode-ray tube through a push-pull arrangement.

For the GATE ADJUST position of the function selector switch, the horizontal-deflection voltage originates in the synchroscope sweep generator. Though the synchroscope sweep generator can be triggered by the detected transmitter pulses from the trigger detector, the generator is normally triggered by an externally applied trigger to permit observation of all the detected radar-transmitter pulses on the CRT indicator. The sweep voltage is taken from the generator to the horizontal amplifier and then applied to the horozontal-deflection plates.

For the PWR-FREQ METER, PULSE MOD, FREQ MOD, and EXT MOD positions of the function selector switch, the synchroscope sweep generator is again used as a source of horizontal-deflection voltage. However, the sweep generator is triggered by either the first detected RF pulse from the trigger detector or by an external trigger as desired.

BLANKING AND INTENSIFYING CIRCUIT

For the MIXER, NORMAL, and GATED positions of the function selector switch, the output from the spectrum sweep generator is differentiated and fed to the blanking and intensifying circuits as a blanking signal. The output of the vertical amplifier is also fed to the blanking and intensifying circuits as an intensifying signal. The signal output is fed through relay K_{101A} to the control grid of the cathode-ray tube and is used to blank the screen during flyback time and to intensify during sweep time. For synchroscope operation, however, an unblanking signal is taken from the synchroscope sweep generator circuits and fed through relay K_{101A} to the CRT control grid for intensifying the sweep.

PULSE GENERATOR ASSEMBLY CIRCUITS

The pulse generator circuit consist of the trigger delay circuits and the pulse modulator circuits. The function of the delay circuit is to control and adjust the starting point of the gating waveform applied to the IF amplifier. With the function selector switch in the GATE ADJ position, it permits centering of the gating pulse over the desired radar-transmitter pulse. When the function selector switch is then switched to the GATED position, only the spectrum of the chosen radar-transmitter pulse is displayed.

For the PULSE MOD position of the function selector switch, a negative pulse is taken from the pulse modulator circuits and applied to the klystron reflector. Then, once for each applied trigger, the klystron is driven into oscillation for the duration of the pulse.

KLYSTRON MODULATION CIRCUITS

The test set klystron oscillator, located physically in the microwave block assembly, operates as a CW signal source depending on the position of the function selection switch and the type of operation desired. For the MIXER, NORMAL, and GATED positions, the klystron is frequency modulated by a sawtooth voltage from the spectrum sweep generator. For the PULSE MOD position of the function selector switch the klystron is pulse modulated by the pulse generator assembly as previously discussed. For the FREQ MOD position, the klystron is switched by relay action to the output of the synchroscope sweep generator. The signal consists of an exponential charging waveform, and its repetition rate depends upon that of the trigger applied to the synchroscope sweep generator. For the EXT MOD position, the EXT MOD connector is switched by relay action directly to the klystron for an external modulation signal input.

POWER-SUPPLY CIRCUIT

The power supply consists of four separate circuits for d-c supply voltages in addition to the a-c filament supply. They are all fed from a common power transformer located in the power-supply assembly.

The high-voltage supply delivers a negative 1,500 volts, unregulated, to the CRT for an accelerating voltage.

The plate and screen supply voltages are taken from a regulated circuit which has four output voltage levels. The primary output, a +300 volts, is supplied to the pulse generator, the klystron oscillator, and to the various circuits. A +500-volt output is used for feeding the pulse generator and power-level bridge circuits. Another +150-volt output is fed to the IF amplifier section. A fourth output of +105 volts supplies the screen-grid circuits of the IF amplifiers.

Biasing voltages are taken from a separate regulated supply. The -205-volt output is the main bias voltage used throughout the test set. A separate -87-volt output is used for the vertical amplifier and spectrum sweep generator biasing voltages.

The fourth d-c supply circuit consists of a full-wave, rectifier bridge circuit which produces a +28-volt d-c supply. This circuit supplies 28 volts d.c. for energizing the relays in the test set and energizing the motor which opens and closes the RF switch in the waveguide.

Theory and Analysis of a Spectrum

Prior to a discussion on the alinement and maintenance of the AN/UPM-32 and for a better understanding of the test set in general, a brief discussion on the basic principles, application, and practical value of a spectrum analysis will be discussed.

BASIC PRINCIPLES

In conventional circuit theory, any repetitive waveform can be analyzed by the use of Fourier equations. This type of analysis shows that a square wave, or any other nonsinusoidal repetitive wave consists of a fundamental sine wave plus an infinite number of harmonics. The pulsed output of a radar transmitter can be treated in the same manner.

The process of modulation inherently produces frequencies other than the modulated or modulating frequencies themselves. When the frequencies resulting from a modulation process are plotted on a horizontal scale and the energy distribution among these frequencies is plotted on a vertical scale, the result is a frequency power plot, more commonly known as a spectrum. Figure 15-24 (D) illustrates the spectrum resulting when a fundamental frequency F is modulated by arbitrarily chosen frequencies F1 and F2. Actually there are an infinite number of frequencies present even in the simple modulation of one sine wave by another, but the amplitudes of the higher-order harmonics are negligible.

If the fundamental frequency F (fig. 15-24 (A)) is modulated by frequency F1, the resultant waveform will appear as illustrated in figure 15-24 (B). In the spectrum pattern (fig. 15-24 (D)), the modulation by F1 causes two other frequencies to appear, F+F1 and F-F1 respectively.

Figure 15-24 (C) shows the effect of modulating the fundamental frequency F with a frequency F2 which is twice the frequency of F1. The result is the appearance of two new frequencies in the spectrum which are indicated as F+F2 and F-F2.

APPLICATION OF PRINCIPLES TO A PULSED OSCILLATOR

Although the duration of a pulse is extremely small compared to the repetition rate in a typical radar system, the output can be visualized for purposes of analysis as a continuous wave of RF energy which is periodically interrupted. This in effect the same as taking the continuous RF wave and modulating it with a repetitive rectangular pulse. Since the pulse itself contains an infinite number of harmonics of its own repetition frequency, each of these harmonic frequencies and the repetition frequency modulate the continuous wave. Hence, a spectrum evolves in the manner explained in the preceding discussion except that there are an infinite number of sideband components.

Figure 15-25 (A) illustrates a theoretical voltage spectrum of a pulsed oscillator. Though not shown, an infinite number of negligibly small sideband components extend from either side of the limits of the diagram. Any two adjacent sideband components are separated by a distance on the frequency scale which is equal to the repetition rate of the rectangular pulses (fig. 15-25 (B)), because each component bears a harmonic relation to the repetition frequency.

Neither of the voltage spectrums shown in figure 15-25 (A) and (C) is actually seen on the test set scope because of a square-law detector incorporated in the test instrument. This detector converts the voltage into the power spectrum illustrated in figure 15-25 (D).

PRACTICAL VALUE OF ANALYSIS

With a knowledge of how a spectrum is formed and what it indicates, it can be seen

30°–44.9°

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
30	sin	0.5000	0.5015	0.5030	0.5045	0.5060	0.5075	0.5090	0.5105	0.5120	0.5135
	cos	0.8660	0.8652	0.8643	0.8634	0.8625	0.8616	0.8607	0.8599	0.8590	0.8581
	tan	0.5774	0.5797	0.5820	0.5844	0.5867	0.5890	0.5914	0.5938	0.5961	0.5985
31	sin	0.5150	0.5165	0.5180	0.5195	0.5210	0.5225	0.5240	0.5255	0.5270	0.5284
	cos	0.8572	0.8563	0.8554	0.8545	0.8536	0.8526	0.8517	0.8508	0.8499	0.8490
	tan	0.6009	0.6032	0.6056	0.6080	0.6104	0.6128	0.6152	0.6176	0.6200	0.6224
32	sin	0.5299	0.5314	0.5329	0.5344	0.5358	0.5373	0.5388	0.5402	0.5417	0.5432
	cos	0.8480	0.8471	0.8462	0.8453	0.8443	0.8434	0.8425	0.8415	0.8406	0.8396
	tan	0.6249	0.6273	0.6297	0.6322	0.6346	0.6371	0.6395	0.6420	0.6445	0.6469
33	sin	0.5446	0.5461	0.5476	0.5490	0.5505	0.5519	0.5534	0.5548	0.5563	0.5577
	cos	0.8387	0.8377	0.8368	0.8358	0.8348	0.8339	0.8329	0.8320	0.8310	0.8300
	tan	0.6494	0.6519	0.6544	0.6569	0.6594	0.6619	0.6644	0.6669	0.6694	0.6720
34	sin	0.5592	0.5606	0.5621	0.5635	0.5650	0.5664	0.5678	0.5693	0.5707	0.5721
	cos	0.8290	0.8281	0.8271	0.8261	0.8251	0.8241	0.8231	0.8221	0.8211	0.8202
	tan	0.6745	0.6771	0.6796	0.6822	0.6847	0.6873	0.6899	0.6924	0.6950	0.6976
35	sin	0.5736	0.5750	0.5764	0.5779	0.5793	0.5807	0.5821	0.5835	0.5850	0.5864
	cos	0.8192	0.8181	0.8171	0.8161	0.8151	0.8141	0.8131	0.8121	0.8111	0.8100
	tan	0.7002	0.7028	0.7054	0.7080	0.7107	0.7133	0.7159	0.7186	0.7212	0.7239
36	sin	0.5878	0.5892	0.5906	0.5920	0.5934	0.5948	0.5962	0.5976	0.5990	0.6004
	cos	0.8090	0.8080	0.8070	0.8059	0.8049	0.8039	0.8028	0.8018	0.8007	0.7997
	tan	0.7265	0.7292	0.7319	0.7346	0.7373	0.7400	0.7427	0.7454	0.7481	0.7508
37	sin	0.6018	0.6032	0.6046	0.6060	0.6074	0.6088	0.6101	0.6115	0.6129	0.6143
	cos	0.7986	0.7976	0.7965	0.7955	0.7944	0.7934	0.7923	0.7912	0.7902	0.7891
	tan	0.7536	0.7563	0.7590	0.7618	0.7646	0.7673	0.7701	0.7729	0.7757	0.7785
38	sin	0.6157	0.6170	0.6184	0.6198	0.6211	0.6225	0.6239	0.6252	0.6266	0.6280
	cos	0.7880	0.7869	0.7859	0.7848	0.7837	0.7826	0.7815	0.7804	0.7793	0.7782
	tan	0.7813	0.7841	0.7869	0.7898	0.7926	0.7954	0.7983	0.8012	0.8040	0.8069
39	sin	0.6293	0.6307	0.6320	0.6334	0.6347	0.6361	0.6374	0.6388	0.6401	0.6414
	cos	0.7771	0.7760	0.7749	0.7738	0.7727	0.7716	0.7705	0.7694	0.7683	0.7672
	tan	0.8098	0.8127	0.8156	0.8185	0.8214	0.8243	0.8273	0.8302	0.8332	0.8361
40	sin	0.6428	0.6441	0.6455	0.6468	0.6481	0.6494	0.6508	0.6521	0.6534	0.6547
	cos	0.7660	0.7649	0.7638	0.7627	0.7615	0.7604	0.7593	0.7581	0.7570	0.7559
	tan	0.8391	0.8421	0.8451	0.8481	0.8511	0.8541	0.8571	0.8601	0.8632	0.8662
41	sin	0.6561	0.6574	0.6587	0.6600	0.6613	0.6626	0.6639	0.6652	0.6665	0.6678
	cos	0.7547	0.7536	0.7524	0.7513	0.7501	0.7490	0.7478	0.7466	0.7455	0.7443
	tan	0.8693	0.8724	0.8754	0.8785	0.8816	0.8847	0.8878	0.8910	0.8941	0.8972
42	sin	0.6691	0.6704	0.6717	0.6730	0.6743	0.6756	0.6769	0.6782	0.6794	0.6807
	cos	0.7431	0.7420	0.7408	0.7396	0.7385	0.7373	0.7361	0.7349	0.7337	0.7325
	tan	0.9004	0.9036	0.9067	0.9099	0.9131	0.9163	0.9195	0.9228	0.9260	0.9293
43	sin	0.6820	0.6833	0.6845	0.6858	0.6871	0.6884	0.6896	0.6909	0.6921	0.6934
	cos	0.7314	0.7302	0.7290	0.7278	0.7266	0.7254	0.7242	0.7230	0.7218	0.7206
	tan	0.9325	0.9358	0.9391	0.9424	0.9457	0.9490	0.9523	0.9556	0.9590	0.9623
44	sin	0.6947	0.6959	0.6972	0.6984	0.6997	0.7009	0.7022	0.7034	0.7046	0.7059
	cos	0.7193	0.7181	0.7169	0.7157	0.7145	0.7133	0.7120	0.7108	0.7096	0.7083
	tan	0.9657	0.9691	0.9725	0.9759	0.9793	0.9827	0.9861	0.9896	0.9930	0.9965
Degs.	**Function**	**0′**	**6′**	**12′**	**18′**	**24′**	**30′**	**36′**	**42′**	**48′**	**54′**

15°–29.9°

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
15	sin	0.2588	0.2605	0.2622	0.2639	0.2656	0.2672	0.2689	0.2706	0.2723	0.2740
	cos	0.9659	0.9655	0.9650	0.9646	0.9641	0.9636	0.9632	0.9627	0.9622	0.9617
	tan	0.2679	0.2698	0.2717	0.2736	0.2754	0.2773	0.2792	0.2811	0.2830	0.2849
16	sin	0.2756	0.2773	0.2790	0.2807	0.2823	0.2840	0.2857	0.2874	0.2890	0.2907
	cos	0.9613	0.9608	0.9603	0.9598	0.9593	0.9588	0.9583	0.9578	0.9573	0.9568
	tan	0.2867	0.2886	0.2905	0.2924	0.2943	0.2962	0.2981	0.3000	0.3019	0.3038
17	sin	0.2924	0.2940	0.2957	0.2974	0.2990	0.3007	0.3024	0.3040	0.3057	0.3074
	cos	0.9563	0.9558	0.9553	0.9548	0.9542	0.9537	0.9532	0.9527	0.9521	0.9516
	tan	0.3057	0.3076	0.3096	0.3115	0.3134	0.3153	0.3172	0.3191	0.3211	0.3230
18	sin	0.3090	0.3107	0.3123	0.3140	0.3156	0.3173	0.3190	0.3206	0.3223	0.3239
	cos	0.9511	0.9505	0.9500	0.9494	0.9489	0.9483	0.9478	0.9472	0.9466	0.9461
	tan	0.3249	0.3269	0.3288	0.3307	0.3327	0.3346	0.3365	0.3385	0.3404	0.3424
19	sin	0.3256	0.3272	0.3289	0.3305	0.3322	0.3338	0.3355	0.3371	0.3387	0.3404
	cos	0.9455	0.9449	0.9444	0.9438	0.9432	0.9426	0.9421	0.9415	0.9409	0.9403
	tan	0.3443	0.3463	0.3482	0.3502	0.3522	0.3541	0.3561	0.3581	0.3600	0.3620
20	sin	0.3420	0.3437	0.3453	0.3469	0.3486	0.3502	0.3518	0.3535	0.3551	0.3567
	cos	0.9397	0.9391	0.9385	0.9379	0.9373	0.9367	0.9361	0.9354	0.9348	0.9342
	tan	0.3640	0.3659	0.3679	0.3699	0.3719	0.3739	0.3759	0.3779	0.3799	0.3819
21	sin	0.3584	0.3600	0.3616	0.3633	0.3649	0.3665	0.3681	0.3697	0.3714	0.3730
	cos	0.9336	0.9330	0.9323	0.9317	0.9311	0.9304	0.9298	0.9291	0.9285	0.9278
	tan	0.3839	0.3859	0.3879	0.3899	0.3919	0.3939	0.3959	0.3979	0.4000	0.4020
22	sin	0.3746	0.3762	0.3778	0.3795	0.3811	0.3827	0.3843	0.3859	0.3875	0.3891
	cos	0.9272	0.9265	0.9259	0.9252	0.9245	0.9239	0.9232	0.9225	0.9219	0.9212
	tan	0.4040	0.4061	0.4081	0.4101	0.4122	0.4142	0.4163	0.4183	0.4204	0.4224
23	sin	0.3907	0.3923	0.3939	0.3955	0.3971	0.3987	0.4003	0.4019	0.4035	0.4051
	cos	0.9205	0.9198	0.9191	0.9184	0.9178	0.9171	0.9164	0.9157	0.9150	0.9143
	tan	0.4245	0.4265	0.4286	0.4307	0.4327	0.4348	0.4369	0.4390	0.4411	0.4431
24	sin	0.4067	0.4083	0.4099	0.4115	0.4131	0.4147	0.4163	0.4179	0.4195	0.4210
	cos	0.9135	0.9128	0.9121	0.9114	0.9107	0.9100	0.9092	0.9085	0.9078	0.9070
	tan	0.4452	0.4473	0.4494	0.4515	0.4536	0.4557	0.4578	0.4590	0.4621	0.4642
25	sin	0.4226	0.4242	0.4258	0.4274	0.4289	0.4305	0.4321	0.4337	0.4352	0.4368
	cos	0.9063	0.9056	0.9048	0.9041	0.9033	0.9026	0.9018	0.9011	0.9003	0.8996
	tan	0.4663	0.4684	0.4706	0.4727	0.4748	0.4770	0.4791	0.4813	0.4834	0.4856
26	sin	0.4384	0.4399	0.4415	0.4431	0.4446	0.4462	0.4478	0.4493	0.4509	0.4524
	cos	0.8988	0.8980	0.8073	0.8965	0.8957	0.8949	0.8942	0.8934	0.8926	0.8918
	tan	0.4877	0.4899	0.4921	0.4942	0.4964	0.4986	0.5008	0.5029	0.5051	0.5073
27	sin	0.4540	0.4555	0.4571	0.4586	0.4602	0.4617	0.4633	0.4648	0.4664	0.4679
	cos	0.8910	0.8902	0.8894	0.8886	0.8878	0.8870	0.8862	0.8854	0.8846	0.8838
	tan	0.5095	0.5117	0.5139	0.5161	0.5184	0.5206	0.5228	0.5250	0.5272	0.5295
28	sin	0.4695	0.4710	0.4726	0.4741	0.4756	0.4772	0.4787	0.4802	0.4818	0.4833
	cos	0.8829	0.8821	0.8813	0.8805	0.8796	0.8788	0.8780	0.8771	0.8763	0.8755
	tan	0.5317	0.5340	0.5362	0.5384	0.5407	0.5430	0.5452	0.5475	0.5498	0.5520
29	sin	0.4848	0.4863	0.4879	0.4894	0.4909	0.4924	0.4939	0.4955	0.4970	0.4985
	cos	0.8746	0.8738	0.8729	0.8721	0.8712	0.8704	0.8695	0.8686	0.8678	0.8669
	tan	0.5543	0.5566	0.5589	0.5612	0.5635	0.5658	0.5681	0.5704	0.5727	0.5750
Degs.	Function	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′

APPENDIX VII

NATURAL SINES, COSINES, AND TANGENTS

0°–14.9°

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
0	sin	0.0000	0.0017	0.0035	0.0052	0.0070	0.0087	0.0105	0.0122	0.0140	0.0157
	cos	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999	0.9999
	tan	0.0000	0.0017	0.0035	0.0052	0.0070	0.0087	0.0105	0.0122	0.0140	0.0157
1	sin	0.0175	0.0192	0.0209	0.0227	0.0244	0.0262	0.0279	0.0297	0.0314	0.0332
	cos	0.9998	0.9998	0.9998	0.9997	0.9997	0.9997	0.9996	0.9996	0.9995	0.9995
	tan	0.0175	0.0192	0.0209	0.0227	0.0244	0.0262	0.0279	0.0297	0.0314	0.0332
2	sin	0.0349	0.0366	0.0384	0.0401	0.0419	0.0436	0.0454	0.0471	0.0488	0.0506
	cos	0.9994	0.9993	0.9993	0.9992	0.9991	0.9990	0.9990	0.9989	0.9988	0.9987
	tan	0.0349	0.0367	0.0384	0.0402	0.0419	0.0437	0.0454	0.0472	0.0489	0.0507
3	sin	0.0523	0.0541	0.0558	0.0576	0.0593	0.0610	0.0628	0.0645	0.0663	0.0680
	cos	0.9986	0.9985	0.9984	0.9983	0.9982	0.9981	0.9980	0.9979	0.9978	0.9977
	tan	0.0524	0.0542	0.0559	0.0577	0.0594	0.0612	0.0629	0.0647	0.0664	0.0682
4	sin	0.0698	0.0715	0.0732	0.0750	0.0767	0.0785	0.0802	0.0819	0.0837	0.0854
	cos	0.9976	0.9974	0.9973	0.9972	0.9971	0.9969	0.9968	0.9966	0.9965	0.9963
	tan	0.0699	0.0717	0.0734	0.0752	0.0769	0.0787	0.0805	0.0822	0.0840	0.0857
5	sin	0.0872	0.0889	0.0906	0.0924	0.0941	0.0958	0.0976	0.0993	0.1011	0.1028
	cos	0.9962	0.9960	0.9959	0.9957	0.9956	0.9954	0.9952	0.9951	0.9949	0.9947
	tan	0.0875	0.0892	0.0910	0.0928	0.0945	0.0963	0.0981	0.0998	0.1016	0.1033
6	sin	0.1045	0.1063	0.1080	0.1097	0.1115	0.1132	0.1149	0.1167	0.1184	0.1201
	cos	0.9945	0.9943	0.9942	0.9940	0.9938	0.9936	0.9934	0.9932	0.9930	0.9928
	tan	0.1051	0.1069	0.1086	0.1104	0.1122	0.1139	0.1157	0.1175	0.1192	0.1210
7	sin	0.1219	0.1236	0.1253	0.1271	0.1288	0.1305	0.1323	0.1340	0.1357	0.1374
	cos	0.9925	0.9923	0.9921	0.9919	0.9917	0.9914	0.9912	0.9910	0.9907	0.9905
	tan	0.1228	0.1246	0.1263	0.1281	0.1299	0.1317	0.1334	0.1352	0.1370	0.1388
8	sin	0.1392	0.1409	0.1426	0.1444	0.1461	0.1478	0.1495	0.1513	0.1530	0.1547
	cos	0.9903	0.9900	0.9898	0.9895	0.9893	0.9890	0.9888	0.9885	0.9882	0.9880
	tan	0.1405	0.1423	0.1441	0.1459	0.1477	0.1495	0.1512	0.1530	0.1548	0.1566
9	sin	0.1564	0.1582	0.1599	0.1616	0.1633	0.1650	0.1668	0.1685	0.1702	0.1719
	cos	0.9877	0.9874	0.9871	0.9869	0.9866	0.9863	0.9860	0.9857	0.9854	0.9851
	tan	0.1584	0.1602	0.1620	0.1638	0.1655	0.1673	0.1691	0.1709	0.1727	0.1745
10	sin	0.1736	0.1754	0.1771	0.1788	0.1805	0.1822	0.1840	0.1857	0.1874	0.1891
	cos	0.9848	0.9845	0.9842	0.9839	0.9836	0.9833	0.9829	0.9826	0.9823	0.9820
	tan	0.1763	0.1781	0.1799	0.1817	0.1835	0.1853	0.1871	0.1890	0.1908	0.1926
11	sin	0.1908	0.1925	0.1942	0.1959	0.1977	0.1994	0.2011	0.2028	0.2045	0.2062
	cos	0.9816	0.9813	0.9810	0.9806	0.9803	0.9799	0.9796	0.9792	0.9789	0.9785
	tan	0.1944	0.1962	0.1980	0.1998	0.2016	0.2035	0.2053	0.2071	0.2089	0.2107
12	sin	0.2079	0.2096	0.2113	0.2130	0.2147	0.2164	0.2181	0.2198	0.2215	0.2232
	cos	0.9781	0.9778	0.9774	0.9770	0.9767	0.9763	0.9759	0.9755	0.9751	0.9748
	tan	0.2126	0.2144	0.2162	0.2180	0.2199	0.2217	0.2235	0.2254	0.2272	0.2290
13	sin	0.2250	0.2267	0.2284	0.2300	0.2318	0.2334	0.2351	0.2368	0.2385	0.2402
	cos	0.9744	0.9740	0.9736	0.9732	0.9728	0.9724	0.9720	0.9715	0.9711	0.9707
	tan	0.2309	0.2327	0.2345	0.2364	0.2382	0.2401	0.2419	0.2438	0.2456	0.2475
14	sin	0.2419	0.2436	0.2453	0.2470	0.2487	0.2504	0.2521	0.2538	0.2554	0.2571
	cos	0.9703	0.9699	0.9694	0.9690	0.9686	0.9681	0.9677	0.9673	0.9668	0.9664
	tan	0.2493	0.2512	0.2530	0.2549	0.2568	0.2586	0.2605	0.2623	0.2642	0.2661
Degs.	Function	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′

of 42.1°, according to the table, is 0.6704. Therefore, side A is 100 x 0.6704, or 67.04 feet long.

PROBLEM 3: In the triangle in figure VI-3 (C), the base is 3 units long, and the altitude is 4 units. What is Θ, and how long is the hypotenuse? SOLUTION: With the information given, the tangent of Θ may be determined. Tan $\Theta = \frac{A}{B} = \frac{4}{3} = 1.33$. Locating the value 1.33 as a tangent value in the table of functions, you find it to be the tangent of 53.2°. Therefore, Θ = 53.2°. Once Θ is known, either the sine or cosine ratio may be used to determine the length of the hypotenuse. The cosine of 53.2° is 0.6004. This indicates that the base of 3 units is 0.6004 x the length of the hypotenuse. Therefore, the hypotenuse is $\frac{3}{0.6004}$, or 5 units in length. Using the sine ratio, the hypotenuse is $\frac{3}{0.7997}$, or 5 units in length.

In the foregoing explanations and problems, the sides of triangles were given in inches, feet and units. In applying trigonometry to a-c circuit problems, these units of measure will be replaced by such measurements as ohms, amperes, volts, and watts. Angle Θ will often be referred to as the phase angle. However, the solution of these a-c problems is accomplished in exactly the same manner as the foregoing problems. Only the units and some terminology are changed.

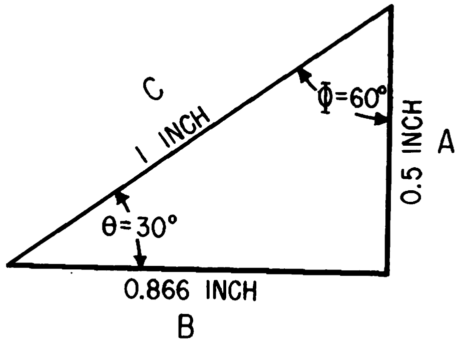


Figure VI-2. —A 30°-60°-90° triangle.

These angular ratios, or sine, cosine, and tangent functions, are listed for each degree and tenth of degree in a table at the end of this appendix. In this table, the length of the hypotenuse of a triangle is considered fixed. Thus, the ratios of length given refer to the manner in which sides A and B vary with relation to each other and in relation to side C, as angle θ is varied from 0° to 90°.

The solution of problems in trigonometry (solution of triangles) is made much simpler when the table of trigonometric functions is used properly. The most common ways in which it is used will be shown by solving a series of exemplary problems.

PROBLEM 1: If the hypotenuse of the triangle (side C) in figure VI-3 (A) is 10 inches long, and angle θ is 33°, how long are sides B and A? SOLUTION: The ratio $\frac{B}{C}$ is the cosine function. By checking the table of functions, you will find that the cosine of 33° is 0.8387. This means that the length of B is 0.8387 the length of side C. If side C is 10 inches long, then side B must be 10 x 0.8387, or 8.387 inches in length. To determine the length of side A, use the sine function, the ratio $\frac{A}{C}$. Again consulting the table of functions, you will find that the sine of 33° is 0.5446. Thus, side A must be 10 x 0.5446, or 5.446 inches in length.

PROBLEM 2: The triangle in figure VI-3 (B) has a base 74.2 feet long, and a hypotenuse 100 feet long. What is θ, and how long is side A? SOLUTION: When no angles are given, you must always solve for a known angle first. The ratio $\frac{B}{C}$ is the cosine of the unknown angle θ; therefore $\frac{74.2}{100}$, or 0.742, is the cosine of the unknown angle. Locating 0.742 as a cosine value in the table, you find that it is the cosine of 42.1°. That is, θ = 42.1°. With θ known, side A is solved for by use of the sine ratio $\frac{A}{C}$. The sine

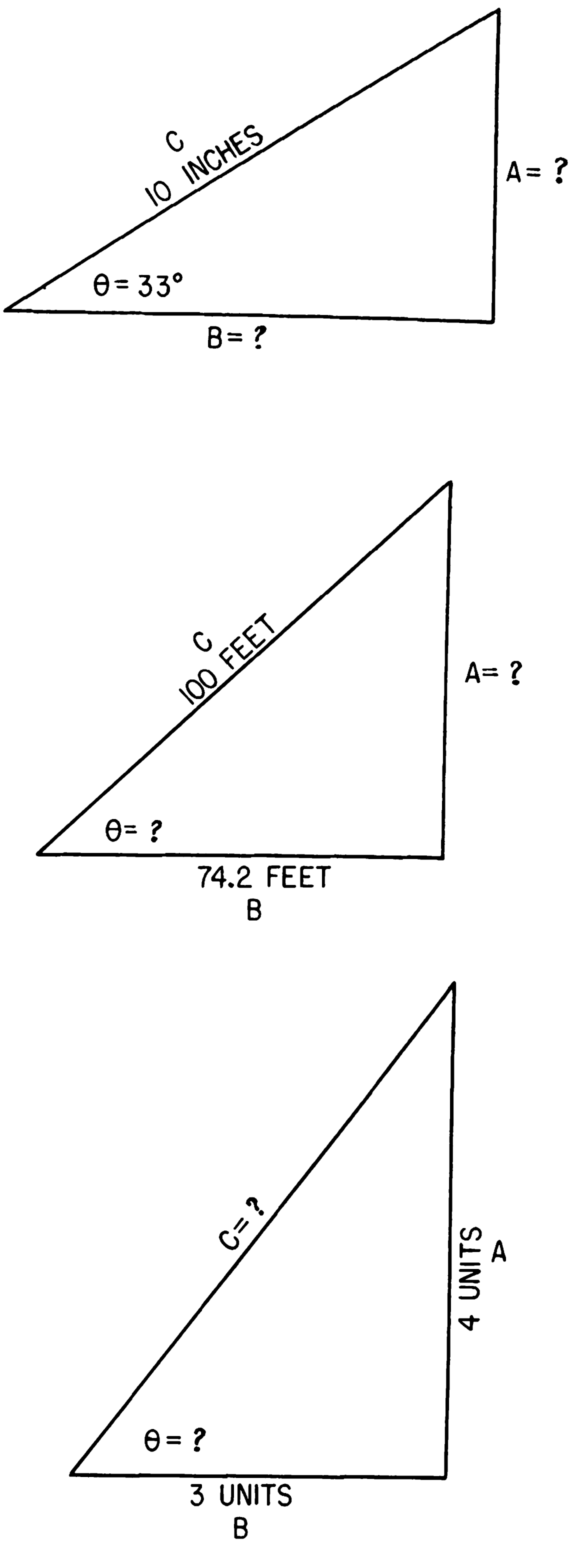


Figure VI-3. —Trigonometric problems.

APPENDIX VI

TRIGONOMETRIC FUNCTIONS

In a right triangle, there are several relationships which always hold true. These relationships pertain to the lengths of the sides of a right triangle, and the way the lengths are affected by the angles between them. An understanding of these relationships, called trigonometric functions, is essential for solving many problems in a-c circuits such as power factor, impedance, voltage drops, and so forth.

To be a RIGHT triangle, a triangle must have a "square" corner; one in which there is exactly 90° between two of the sides. Trigonometric functions do not apply to any other type of triangle. This type of triangle is shown in figure VI-1.

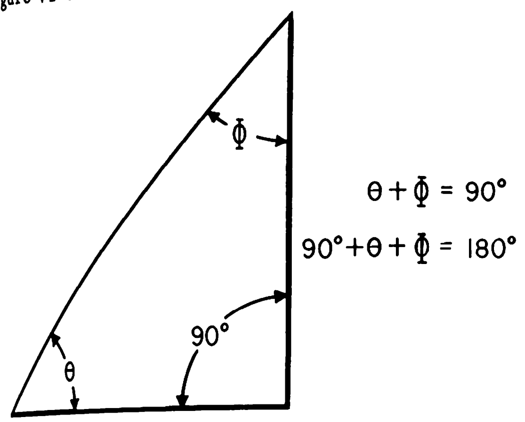


Figure VI-1.—A right triangle.

By use of the trigonometric functions, it is possible to determine the UNKNOWN length of one or more sides of a triangle, or the number of degrees in UNKNOWN angles, depending on what is presently known about the triangle. For instance, if the lengths of any two sides are known, the third side and both angles Θ (theta) and Φ (phi) may be determined. The triangle may also be solved if the length of any one side and one of the angles (Θ or Φ in fig. VI-1) are known.

The first basic fact to accept, regarding triangles, is that in any triangle, the sum of the three angles formed inside the triangle must always equal 180°. If one angle is always 90° (a right angle) then the sum of the other two angles must always be 90°.

$$\Theta + \Phi = 90°$$

and $$90° + \Theta + \Phi = 180°$$

or $$90° + 90° = 180°$$

Thus, if angle Θ is known, Φ may be quickly determined.

For instance, if Θ is 30°, what is Φ?

$$90° + 30° + \Phi = 180°$$

Transposing $$\Phi = 180° - 90° - 30°$$

$$\Phi = 60°$$

Also, if Φ is known, Θ may be determined in the same manner.

The second basic fact you must understand is that for every different combination of angles in a triangle, there is a definite ratio between the lengths of the three sides. Consider the triangle in figure VI-2, consisting of the base, side B; the altitude, side A; and the hypotenuse, side C. (The hypotenuse is always the longest side, and is always opposite the 90° angle.) If angle Θ is 30°, Φ must be 60°. With Θ equal to 30°, the ratio of the length of side B to side C is 0.866 to 1. That is, if the hypotenuse is 1 inch long, the side adjacent to Θ, side B, is 0.866 inch long. Also, with Θ equal to 30°, the ratio of side A to side C is 0.5 to 1. That is, with the hypotenuse 1 inch long, the side opposite to Θ (side A) is 0.5 inch long. With Θ still at 30°, side A is 0.5774 of the length of B. With the combination of angles given (30° - 60° - 90°) these are the ONLY ratios of lengths that will "fit" to form a right triangle.

Note that three ratios are shown to exist for the given value of Θ: the ratio $\frac{B}{C}$, which is always referred to as the COSINE ratio of Θ, the ratio $\frac{A}{C}$, which is always the SINE ratio of Θ, and the ratio $\frac{A}{B}$, which is always the TANGENT ratio of Θ. If Θ changes, all three ratios change, because the lengths of the sides (base and altitude) change. There is a set of ratios for every increment between 0° and 90°.

APPENDIX V

LAWS OF EXPONENTS

The following table shows some multiples of 10 and their equivalent powers of ten which are used to write a number in scientific form.

NUMBER	POWERS OF TEN	NUMBER	POWERS OF TEN
100,000 =	10^5	0.00001 =	10^{-5}
10,000 =	10^4	0.0001 =	10^{-4}
1,000 =	10^3	0.001 =	10^{-3}
100 =	10^2	0.01 =	10^{-2}
10 =	10^1	0.1 =	10^{-1}
1 =	10^0	1. =	10^0

To multiply like (with same base) exponential quantities, add the exponents. In the language of algebra the rule is $a^m \times a^n = a^{m+n}$

$$10^4 \times 10^2 = 10^{4+2} = 10^6$$

$$0.003 \times 825.2 = 3 \times 10^{-3} \times 8.252 \times 10^2$$

$$= 24.756 \times 10^{-1} = 2.4756$$

To divide like exponential quantities, subtract the exponents. In the language of algebra the rule is

$$\frac{a^m}{a^n} = a^{m-n} \text{ or}$$

$$10^8 \div 10^2 = 10^6$$

$$3,000 \div 0.015 = (3 \times 10^3) \div (1.5 \times 10^{-2})$$

$$= 2 \times 10^5 = 200,000$$

To raise an exponential quantity to a power, multiply the exponents. In the language of algebra $(x^m)^n = x^{mn}$.

$$(10^3)^4 = 10^{3\times 4} = 10^{12}$$

$$2,500^2 = (2.5 \times 10^3)^2 = 6.25 \times 10^6 = 6,250,000$$

Any number (except zero) raised to the zero power is one. In the language of algebra $x^0 = 1$

$$x^3 \div x^3 = 1$$

$$10^4 \div 10^4 = 1$$

Any base with a negative exponent is equal to 1 divided by the base with an equal positive exponent. In the language of algebra $x^{-a} = \frac{1}{x^a}$

$$10^{-2} = \frac{1}{10^2} = \frac{1}{100}$$

$$5a^{-3} = \frac{5}{a^3}$$

$$(6a)^{-1} = \frac{1}{6a}$$

To raise a product to a power, raise each factor of the product to that power.

$$(2 \times 10)^2 = 2^2 \times 10^2$$

$$3,000^3 = (3 \times 10^3)^3 = 27 \times 10^9$$

To find the nth root of an exponential quantity, divide the exponent by the index of the root. Thus, the nth root of $a^m = a^{m/n}$.

$$\sqrt{x^6} = x^{6/2} = x^3$$

$$\sqrt[3]{64 \times 10^3} = 4 \times 10 = 40$$

Average power = peak power x duty cycle

$$\text{Peak power} = \frac{\text{average power} \times 10^6}{\text{pulse width in } \mu \text{ sec.} \times \text{PRF}}$$

Secondary current

$$I_s = I_p \frac{N_p}{N_s}$$

Secondary voltage

$$E_s = E_p \frac{N_s}{N_p}$$

THREE-PHASE VOLTAGE AND CURRENT RELATIONSHIPS

With wye connected windings

$$E_{line} = 1.732 E_{coil} = \sqrt{3}\ E_{coil}$$

$$I_{line} = I_{coil}$$

With delta connected windings

$$E_{line} = E_{coil}$$

$$I_{line} = 1.732 I_{coil}$$

With wye or delta connected winding

$$P_{coil} = E_{coil} I_{coil}$$

$$P_t = 3P_{coil}$$

$$P_t = 1.732 E_{line} I_{line}$$

(To convert to true power multiply by $\cos\theta$)

RESONANCE

At resonance

$$X_L = X_C$$

Resonant frequency

$$F_o = \frac{1}{2\pi \sqrt{LC}}$$

Series resonance

$$Z \text{ (at any frequency)} = R + j(X_L - X_C)$$

$$Z \text{ (at resonance)} = R$$

Parallel resonance

$$Z \text{ (at any frequency)} = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

$$Z_{max} \text{ (at resonance)} = \frac{X_L X_C}{R} = \frac{X_L^2}{R} = QX_L = \frac{L}{CR}$$

Band width

$$\Delta = \frac{F_o}{Q} = \frac{R}{2\pi L}$$

TUBE CHARACTERISTICS

Amplification factor

$$\mu = \frac{\Delta e_p}{\Delta e_g} \text{ (} i_p \text{ constant)}$$

$$M = g_m r_p$$

A-c plate resistance

$$r_p = \frac{\Delta e_p}{\Delta i_p} \text{ (} e_g \text{ constant)}$$

Grid-plate transconductance

$$g_m = \frac{\Delta i_p}{\Delta e_g} \text{ (} e_p \text{ constant)}$$

DECIBELS

Power ratio

$$db = 10 \log_{10} \frac{P_2}{P_1}$$

Current and voltage ratio

$$db = 20 \log_{10} \frac{I_2 \sqrt{R_2}}{I_1 \sqrt{R_1}}$$

$$db = 20 \log_{10} \frac{E_2 \sqrt{R_1}}{E_1 \sqrt{R_2}}$$

NOTE: When R_1 and R_2 are equal they may be omitted from the formula.

When reference level is one milliwatt

$$dbm = 10 \log_{10} \frac{P}{0.001} \text{ (when P is in watts)}$$

SYNCHRONOUS SPEED OF MOTOR

$$r.p.m. = \frac{120 \times \text{frequency}}{\text{number of poles}}$$

RADAR POWER RELATIONSHIPS

$$\text{Duty cycle} = \frac{\text{average power}}{\text{peak power}}$$

$$= \frac{\text{pulse width}}{\text{pulse repetition time}}$$

Appendix IV—FORMULAS

Comparison of Units in Electric and Magnetic Circuits

	Electric circuit	Magnetic circuit
Force	Volt, E, or e.m.f.	Gilberts, F, or m.m.f.
Flow	Ampere, I	Flux, Φ, in maxwells
Opposition	Ohms, R	Reluctance, $\mathcal{R}$
Law	Ohm's law, $I = \frac{E}{R}$	Rowland's law, $\Phi = \frac{F}{\mathcal{R}}$
Intensity of force	Volts per cm of length	$H = \frac{1.257IN}{L}$, gilberts per centimeter of length
Density	Current density—for example, amperes per cm^2	Flux density—for example, lines per cm^2, or gausses

Q OF A COIL

$$Q = \frac{X_L}{R}$$

IMPEDANCE OF AN RL CIRCUIT (SERIES)

$$Z = \sqrt{R^2 + X_L{}^2}$$

IMPEDANCE WITH R, C, AND L IN SERIES

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

PARALLEL CIRCUIT IMPEDANCE

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

SINE-WAVE VOLTAGE RELATIONSHIPS

Average value

$$E_{ave} = \frac{2}{\pi} \times E_{max} = 0.637E_{max}$$

Effective or r. m. s. value

$$E_{eff} = \frac{E_{max}}{\sqrt{2}} = \frac{E_{max}}{1.414} = 0.707E_{max} = 1.11E_{ave}$$

Maximum value

$$E_{max} = \sqrt{2}E_{eff} = 1.414E_{eff} = 1.57E_{ave}$$

Voltage in an a-c circuit

$$E = IZ = \frac{P}{I \times P.F.}$$

Current in an a-c circuit

$$I = \frac{E}{Z} = \frac{P}{E \times P.F.}$$

POWER IN A-C CIRCUIT

Apparent power = EI
True power

$$P = EI \cos\theta = EI \times P.F.$$

Power Factor

$$P.F. = \frac{P}{EI} = \cos\theta$$

$$\cos\theta = \frac{\text{true power}}{\text{apparent power}}$$

TRANSFORMERS

Voltage relationship

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \text{ or } E_s = E_p \times \frac{N_s}{N_p}$$

Current relationship

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Induced voltage

$$E_{eff} = 4.44\ BAfN \times 10^{-8}$$

Turns ratio equals

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

APPENDIX IV

FORMULAS

OHM'S LAW FOR D-C CIRCUITS

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2R$$

RESISTORS IN SERIES

$$R_T = R_1 + R_2 \ldots$$

RESISTORS IN PARALLEL

Two resistors

$$R_T = \frac{R_1R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$$

RL CIRCUIT TIME CONSTANT

$$\frac{L \text{ (in henrys)}}{R \text{ (in ohms)}} = t \text{ (in seconds), or}$$

$$\frac{L \text{ (in microhenrys)}}{R \text{ (in ohms)}} = t \text{ (in microseconds)}$$

RC CIRCUIT TIME CONSTANT

R (ohms) x C (farads) = t (seconds)
R (megohms) x C (microfarads) = t (seconds)
R (ohms) x C (microfarads) = t (microseconds)
R (megohms) x C (micromicrofarads) = t (microseconds)

CAPACITORS IN SERIES

Two capacitors

$$C_T = \frac{C_1C_2}{C_1 + C_2}$$

More than two

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \ldots$$

CAPACITORS IN PARALLEL

$$C_T = C_1 + C_2 \ldots$$

CAPACITIVE REACTANCE

$$X_C = \frac{1}{2\pi fC}$$

IMPEDANCE IN AN RC CIRCUIT (SER

$$Z = \sqrt{R^2 + X_C{}^2}$$

INDUCTORS IN SERIES

$L_T = L_1 + L_2 \ldots$ (No coupling betwee

INDUCTORS IN PARALLEL

Two inductors

$L_T = \frac{L_1L_2}{L_1 + L_2}$ (No coupling between

More than two

$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \ldots$ (No coupling b coils)

INDUCTIVE REACTANCE

$$X_L = 2\pi fL$$

APPENDIX III

GREEK ALPHABET

Name	Capital	Lower case	Designates
Alpha	Α	α	Angles.
Beta	Β	β	Angles, flux density.
Gamma	Γ	γ	Conductivity.
Delta	Δ	δ	Variation of a quantity, increment.
Epsilon	Ε	ϵ	Base of natural logarithms (2.71828).
Zeta	Ζ	ζ	Impedance, coefficients, coordinates.
Eta	Η	η	Hysteresis coefficient, efficiency.
Theta	Θ	θ	Phase angle
Iota	Ι	ι	
Kappa	Κ	κ	Dielectric constant, coupling coefficient, susceptibility.
Lambda	Λ	λ	Wavelength.
Mu	Μ	μ	Permeability, micro, amplification factor.
Nu	Ν	ν	Reluctivity.
Xi	Ξ	ξ	
Omicron	Ο	ο	
Pi	Π	π	3.1416
Rho	Ρ	ρ	Resistivity.
Sigma	Σ	σ	
Tau	Τ	τ	Time constant, time-phase displacement.
Upsilon	Υ	υ	
Phi	Φ	ϕ	Angles, magnetic flux.
Chi	Χ	χ	
Psi	Ψ	ψ	Dielectric flux, phase difference.
Omega	Ω	ω	Ohms (capital), angular velocity ($2\pi f$).

TERM	ABBREVIATION OR SYMBOL
root mean square	r.m.s.
tera (10^{12})	T
time	t
torque	T
volt	v.
watt	w.

THERMISTOR.—A resistor that is used to compensate for temperature variations in a circuit.

THERMOCOUPLE.—A junction of two dissimilar metals that produces a voltage when heated.

TRACE.—A visible line or lines appearing on the screen of a cathode-ray tube in operation.

TRANSFORMER.—A device composed of two or more coils, linked by magnetic lines of force, used to transfer energy from one circuit to another.

TRANSMISSION LINES.—Any conductor or system of conductors used to carry electrical energy from its source to a load.

TRIGGERING.—Starting an action in another circuit, which then functions for a time under its own control.

TRIODE.—A three-electrode vacuum tube, containing a cathode, control grid, and plate.

TUNED CIRCUIT.—A resonant circuit.

VACUUM TUBE.—An evacuated envelope containing two or more electrodes.

VECTOR.—A line used to represent both direction and magnitude.

VIDEO AMPLIFIER.—A circuit capable of amplifying a very wide range of frequencies, including and exceeding the audio band of frequencies.

VOLT.—The unit of electrical potential.

WATT.—The unit of electrical power.

WATTMETER.—An instrument for measuring electric power in watts.

WAVEFORM.—The shape of the wave obtained when instantaneous values of an a-c quantity are plotted against time in rectangular coordinates.

WAVELENGTH (λ).—The distance, usually expressed in meters, traveled by a wave during the time interval of one complete cycle. It is equal to the velocity divided by the frequency.

ZENER DIODE.—A solid state semiconductor that has voltage regulation characteristics when subjected to reversed bias.

COMMON ABBREVIATIONS AND LETTER SYMBOLS

TERM	ABBREVIATION OR SYMBOL
alternating current (noun)	a.c.
alternating current (adj)	a-c
ampere	a.
area	A
audiofrequency (noun)	AF
audiofrequency (adj)	A-F
capacitance	C
capacitive reactance	X_C
centi (10^{-2})	c
centimeter	cm.
conductance	G
coulomb	Q
counterelectromotive force	c.e.m.f.
current (d-c or r.m.s. value)	I
current (instantaneous value)	i
deci (10^{-1})	d
deka (10)	dk
dielectric constant	K,k
difference in potential (d-c or r.m.s. value)	E
difference in potential (instantaneous value)	e
direct current (noun)	d.c.
direct current (adj)	d-c
electromotive force	e.m.f.
frequency	f
giga (10^9)	G
hecto (10^2)	h
henry	h.
horsepower	hp.

TERM	ABBREVIATION OR SYMBOL
impedance	Z
inductance	L
inductive reactance	X_L
kilo (10^3)	k
kilovolt	kv.
kilovolt-ampere	kv.-a.
kilowatt	kw.
kilowatt-hour	kw.-hr.
magnetic field intensity	H
magnetomotive force	m.m.f.
mega (10^6)	M
megohm	MΩ
micro (10^{-6})	μ
microampere	μa
microfarad	μf
microhenry	μh
micromicrofarad	μμf
microvolt	μv
milli (10^{-3})	m
milliampere	ma.
millihenry	mh.
milliwatt	mw.
mutual inductance	M
nano (10^{-9})	n
ohm	Ω
pico (10^{-12})	p
picofarad	pf
power	P
resistance	R
revolutions per minute	r.p.m.

POSITIVE CHARGE.--The electrical charge carried by a body which has become deficient in electrons.

POTENTIAL.--The amount of charge held by a body as compared to another point or body. Usually measured in volts.

POTENTIOMETER.--A variable voltage divider; a resistor which has a variable contact arm so that any portion of the potential applied between its ends may be selected.

POWER.--The rate of doing work or the rate of expending energy. The unit of electrical power is the watt.

POWER FACTOR.--The ratio of the actual power of an alternating or pulsating current, as measured by a wattmeter, to the apparent power, as indicated by ammeter and voltmeter readings. The power factor of an inductor, capacitor, or insulator is an expression of their losses.

PRIME MOVER.--The source of mechanical power used to drive the rotor of a generator.

PROTON.--A positively charged particle in the nucleus of an atom.

PUSH-PULL CIRCUIT.--A push-pull circuit usually refers to an amplifier circuit using two vacuum tubes in such a fashion that when one vacuum tube. is operating on a positive alternation, the other vacuum tube operates on a negative alternation.

RATIO.--The value obtained by dividing one number by another, indicating their relative proportions.

REACTANCE.--The opposition offered to the flow of an alternating current by the inductance, capacitance, or both, in any circuit.

RECIPROCAL.--The value obtained by dividing the number 1 by any quantity.

RECTIFIERS.--Devices used to change alternating current to unidirectional current. These may be vacuum tubes, semiconductors such as germanium and silicon, dry-disk rectifiers such as selenium and copper-oxide, and also certain types of crystal.

RELAXATION OSCILLATOR.--A circuit for the generation of nonsinusoidal waves by gradually storing and quickly releasing energy either in the electric field of a capacitor or in the magnetic field of an inductor.

RELAY.--An electromechanical switching device that can be used as a remote control.

RELUCTANCE.--A measure of the opposition that a material offers to magnetic lines of force.

RESISTANCE.--The opposition to the flow of current caused by the nature and physical dimensions of a conductor.

RESISTOR.--A circuit element whose chief characteristic is resistance; used to oppose the flow of current.

RESONANCE.--The condition existing i
cuit in which the inductive and ca
reactances cancel each other.

RESONANCE CURVE.--A graphical repr
tion of the manner in which a r
circuit responds to various freque
and near the resonant frequency.

RETENTIVITY.--The measure of the a
a material to hold its magnetism.

REVERBERATION.--The continuation o
by excessive reflection.

RHEOSTAT.--A variable resistor.

SATURABLE REACTOR.--A control dev
uses a small d-c current to control
a-c current by controlling core flux

SATURATION.--The condition existing
circuit when an increase in the drivin
produces no further change in the r
effect.

SELF-INDUCTION.--The process by
circuit induces an e.m.f. into itsel
own magnetic field.

SERIES-WOUND.--A motor or gener
which the armature is wired in ser
the field winding.

SERVO.--A device used to convert a
movement into one of greater mo
or force.

SERVOMECHANISM.--A closed-loop syst
produces a force to position an o
accordance with the information tha
nates at the input.

SOLENOID.--An electromagnetic coil th
tains a movable plunger.

SPACE CHARGE.--The cloud of electron
ing in the space between the catho
plate in a vacuum tube, formed by th
trons emitted from the cathode in
of those immediately attracted to th

STANDING WAVE.--A distribution of
and voltage on a transmission line fo
two sets of waves traveling in o
directions, and characterized by the p
of a number of points of successive
and minima in the distribution curve

STATIC.--A fixed nonvarying condition;
motion.

SWEEP CIRCUIT.--The part of a catho
oscilloscope which provides a time-re
base.

SYNCHRONOUS.--Happening at the sam
having the same period and phase.

SYNCHRO SYSTEM.--An electrical syst
gives remote indications or control b
of self-synchronizing motors.

TACHOMETER.--An instrument for ind
revolutions per minute.

TERTIARY WINDING.--A third windin
transformer or magnetic amplifier
used as a second control winding.

LINEAR.—Having an output which varies in direct proportion to the input.

LINE OF FORCE.—A line in an electric or magnetic field that shows the direction of the force.

LOAD.—The power that is being delivered by any power producing device. The equipment that uses the power from the power producing device.

MAGNETIC AMPLIFIER.—A saturable reactor type device that is used in a circuit to amplify or control.

MAGNETIC CIRCUIT.—The complete path of magnetic lines of force.

MAGNETIC FIELD.—The space in which a magnetic force exists.

MAGNETIC FLUX.—The total number of lines of force issuing from a pole of a magnet.

MAGNETIZE.—To convert a material into a magnet by causing the molecules to rearrange.

MAGNETO.—A generator which produces alternating current and has a permanent magnet as its field.

MAGNETRON.—A vacuum-tube oscillator containing two electrodes, in which the flow of electrons from cathode to anode is controlled by an externally applied magnetic field.

MEGGER.—A test instrument used to measure insulation resistance and other high resistances. It is a portable hand-operated d-c generator used as an ohmmeter.

MEGOHM.—A million ohms.

MHO.—The unit of conductance, which is the reciprocal of resistance.

MICRO.—A prefix meaning one-millionth.

MILLI.—A prefix meaning one-thousandth.

MILLIAMMETER.—An ammeter that measures in thousandths of an ampere.

MODULATION.—The process of varying the amplitude (amplitude modulation), the frequency (frequency modulation), or the phase (phase modulation) of a carrier wave in accordance with other signals in order to convey intelligence. The modulating signal may be an audiofrequency signal, video signal (as in television), or electrical pulses or tones to operate relays, etc.

MOLECULE.—The atom or group of atoms that constitute the smallest particle in which a compound or material can exist separately.

MOTOR-GENERATOR.—A motor and a generator with a common shaft used to convert line voltages to other voltages or frequencies.

MUTUAL INDUCTANCE.—A circuit property existing when the relative position of two inductors causes the magnetic lines of force from one to link with the turns of the other.

NEGATIVE CHARGE.—The electrical charge carried by a body which has an excess of electrons.

NEUTRONS.—A particle having the weight of a proton but carrying no electric charge. It is located in the nucleus of an atom.

NONLINEAR.—Having an output which does not vary in direct proportion to the input.

NUCLEUS.—The central part of an atom that is mainly comprised of protons and neutrons. It is the part of the atom that has the most mass.

NULL.—Zero.

OCTODE.—A vacuum tube having eight electrodes.

OHM.—The unit of electrical resistance.

OHMMETER.—An instrument for directly measuring resistance in ohms.

OSCILLOSCOPE.—An instrument for showing, visually, graphical representations of the waveforms encountered in electrical circuits.

OVERLOAD.—A load greater than the rated load of an electrical device.

PERMALLOY.—An alloy of nickel and iron having an abnormally high magnetic permeability.

PERMEABILITY.—A measure of the ease with which magnetic lines of force can flow through a material as compared to air.

PHASE DIFFERENCE.—The time in electrical degrees by which one wave leads or lags another.

PHOSPHORESCENCE.—The property of emitting light for some time after excitation by electronic bombardment.

PLATE.—The principal electrode in a tube to which the electron stream is attracted.

PLATE CURRENT.—The current flowing in the plate circuit of a vacuum tube.

PLATE DETECTION.—The operation of a vacuum-tube detector at or near cutoff so that the input signal is rectified in the plate circuit.

PLATE RESISTANCE (r_p).—The internal resistance to the flow of alternating current between the cathode and plate of a tube. It is equal to a small change in plate voltage divided by the corresponding change in plate current, and is expressed in ohms. It is also called a-c resistance, internal impedance, plate impedance, and dynamic plate impedance. The static plate resistance, or resistance to the flow of direct current, is a different value.. It is denoted by R_p.

POLARITY.—The character of having magnetic poles, or electric charges.

POLE.—The section of a magnet where the flux lines are concentrated; also where they enter and leave the magnet. An electrode of a battery.

POLYPHASE.—A circuit that utilizes more than one phase of alternating current.

FREE ELECTRONS.--Electrons which are loosely held and consequently tend to move at random among the atoms of the material.

FREQUENCY.--The number of complete cycles per second existing in any form of wave motion; such as the number of cycles per second of an alternating current.

FULL-WAVE RECTIFIER CIRCUIT.--A circuit which utilizes both the positive and the negative alternations of an alternating current to produce a direct current.

FUSE.--A protective device inserted in series with a circuit. It contains a metal that will melt or break when current is increased beyond a specific value for a definite period of time.

GAIN.--The ratio of the output power, voltage, or current to the input power, voltage, or current, respectively.

GALVANOMETER.--An instrument used to measure small d-c currents.

GAS TUBE.--A tube that gives certain electrical characteristics because it is filled with a certain type of gas.

GATING (CATHODE-RAY TUBE).--Applying a rectangular voltage to the grid or cathode of a CRT to sensitize it during the sweep time only.

GENERATOR.--A machine that converts mechanical energy into electrical energy.

GRID.--A wire, usually in the form of a spiral, that controls the electron flow in a vacuum tube.

GRID DETECTION: Detection by rectification in the grid circuit of a detector.

GRID LEAK.--A high resistance connected across the grid capacitor or between the grid and the cathode to provide a d-c path from grid to cathode and to limit the accumulation of charge on the grid.

GROUND.--A metallic connection with the earth to establish ground potential. Also, a common return to a point of zero potential. The chassis of a receiver or a transmitter is sometimes the common return, and therefore the ''ground'' of the unit.

HARMONIC.--An integral multiple of a fundamental frequency. (The second harmonic is twice the frequency of the fundamental or first harmonic.)

HENRY.--The basic unit of inductance.

HEPTODE.--A vacuum tube having seven electrodes.

HETERODYNE.--To beat or mix two signals of different frequencies.

HEXODE.--A vacuum tube having six electrodes.

HOLE.--In semiconductors, the space in an atom left vacant by a departed electron. Holes flow in a direction opposite to that of electrons, are considered to be current carriers, and bear a positive charge.

HORSEPOWER.--The English unit of
equal to work done at the rate of 5
pounds per second. Equal to 746 v
electrical power.

HYSTERESIS.--A lagging of the magne
in a magnetic material behind the
netizing force which is producing it.

IMPEDANCE.--The total opposition off
the flow of an alternating current.
consist of any combination of resi
inductive reactance, and capaciti
actance.

INCIDENT WAVE.--A wave striking an

INDUCTANCE.--The property of a circu
tends to oppose a change in the
current.

INDUCTION.--The act or process of pr
voltage by the relative motion of a m
field across a conductor.

INDUCTIVE REACTANCE.--The opposi
the flow of alternating or pulsating
caused by the inductance of a circu
measured in ohms.

INDUCTOR.--A circuit element designed
its inductance is its most importan
trical property; a coil.

INPHASE.--Applied to the condition that
when two waves of the same frequen
through their maximum and minimum
of like polarity at the same instant.

INTENSITY MODULATION.--The contro
brilliance of the trace on the scre
cathode-ray tube in conformity w
signal.

INVERSELY.--Inverted or reversed in p
or relationship.

ISOGONIC LINE.--An imaginary line
through points on the earth's surface
the magnetic deviation is equal.

JOULE.--A unit of energy or work. A j
energy is liberated by one ampere
for one second through a resistance
ohm.

KILO.--A prefix meaning 1,000.

KLYSTRON.--A tube in which oscillatio
generated by the bunching of electron
is, velocity modulation). This tube u
the transit time between two given elec
to deliver pulsating energy to a
resonator in order to sustain oscil
within the cavity.

KNEE.--An abrupt change in direction be
two fairly straight segments of a curv

LAG.--The amount one wave is behind a
in time; expressed in electrical degre

LAMINATED CORE.--A core built up fro
sheets of metal and used in transfo
and relays.

LEAD.--The opposite of LAG. Also, a w
connection.

COAXIAL CABLE.--A transmission line consisting of two conductors concentric with and insulated from each other.

COMMUTATOR.—The copper segments on the armature of a motor or generator. It is cylindrical in shape and is used to pass power into or from the brushes. It is a switching device.

CONDUCTANCE.—The ability of a material to conduct or carry an electric current. It is the reciprocal of the resistance of the material, and is expressed in mhos.

CONDUCTIVITY.—The ease which a substance transmits electricity.

CONDUCTOR.—Any material suitable for carrying electric current.

CONTACT RECTIFIER.—Two different solids in contact, in which rectification is due to greater conductivity across the contact in one direction than the other.

CORE.—A magnetic material that affords an easy path for magnetic flux lines in a coil.

COULOMB.—A unit of electrical charge; the quantity of electrical charge created by a steady flow of one ampere for one second.

COUNTER E. M. F.—Counter electromotive force; an e.m.f. induced in a coil or armature that opposes the applied voltage.

COUNTING CIRCUIT.—A circuit which receives uniform pulses representing units to be counted and produces a voltage in proportion to their frequency.

CURRENT LIMITER.—A protective device similar to a fuse, usually used in high amperage circuits.

CYCLE.—One complete positive and one complete negative alternation of a current or voltage.

DETECTION.—The process of separating the modulation component from the received signal.

DIELECTRIC.—An insulator; a term that refers to the insulating material between the plates of a capacitor.

DIODE.—Vacuum tube—a two element tube that contains a cathode and plate; semiconductor—a material of either germanium or silicon that is manufactured to allow current to flow in only one direction. Diodes are used as rectifiers and detectors.

DIRECT CURRENT.--An electric current that flows in one direction only.

DISTORTION.—The production of an output waveform which is not a true reproduction of the input waveform. Distortion may consist of irregularities in amplitude, frequency, or phase.

DOPPLER EFFECT.—An apparent change in the frequency of a sound or electromagnetic wave reaching a receiver when there is relative motion between the source and the receiver.

DUCT.—An atmospheric phenomenon consisting of two layers between which electromagnetic waves are channeled.

EDDY CURRENT.—Induced circulating currents in a conducting material that are caused by a varying magnetic field.

EFFICIENCY.—The ratio of output power to input power, generally expressed as a percentage.

ELECTRICITY.--The science which treats of the phenomena and laws of things electrical.

ELECTRODE.--A terminal used to emit, collect, or control electrons and ions; a terminal at which electric current passes from one medium into another.

ELECTROLYSIS.—Corrosion caused by a current flowing in and out of the surface of a conductor.

ELECTROLYTE.--A solution of a substance which is capable of conducting electricity. An electrolyte may be in the form of either a liquid or a paste.

ELECTROMAGNET.--A magnet made by passing current through a coil of wire wound on a soft iron core.

ELECTROMOTIVE FORCE (E.M.F.).--The force that produces an electric current in a circuit.

ELECTRON.--A negatively charged particle of matter.

ELECTRON EMISSION.--The liberation of electrons from a body into space under the influence of heat, light, impact, chemical disintegration, or potential difference.

ELECTRONIC SWITCH.--A circuit which causes a start-and-stop action or a switching action by electronic means.

ENERGY.--The ability or capacity to do work.

EQUIVALENT CIRCUIT.--A diagrammatic arrangement of coils, resistors, and capacitors, representing the effects of a more complicated circuit in order to permit easier analysis.

FARAD.—The unit of capacitance.

FEEDBACK.—A transfer of energy from the output circuit of a device back to its input.

FIELD.--The space containing electric or magnetic lines of force.

FIELD WINDING.—The coil used to provide the magnetizing force in motors and generators.

FILTERS.—A combination of circuit elements designed to pass a definite range of frequencies, attenuating all others.

FLUORESCENCE.—The property of emitting light as the immediate result of electronic bombardment.

FLUX FIELD.--All electric or magnetic lines of force in a given region.

APPENDIX II

TERMS AND ABBREVIATIONS

ELECTRONICS AND ELECTRICAL TERMS

AGONIC.--An imaginary line of the earth's surface passing through points where the magnetic declination is 0°; that is, points where the compass points to true north.

AMMETER.--An instrument for measuring the amount of electron flow in amperes.

AMPERE.--The basic unit of electrical current.

AMPERE-TURN.--The magnetizing force produced by a current of one ampere flowing through a coil of one turn.

AMPLIFICATION.--The process of increasing the strength (current, power, or voltage) of a signal.

AMPLIFICATION FACTOR (μ).--The ratio of a small change in plate voltage to a small change in grid voltage, with all other electrode voltages constant, required to produce the small change in plate current.

AMPLIFIER.—A device used to increase the signal voltage, current, or power, generally composed of a vacuum tube and associated circuit called a stage. It may contain several stages in order to obtain a desired gain.

AMPLITUDE.—The maximum instantaneous value of an alternating voltage or current, measured in either the positive or negative direction.

ANODE.—A positive electrode; the plate of a vacuum tube.

AQUADAG.—A graphite coating on the inside of certain cathode-ray tubes for collecting secondary electrons emitted by the screen.

ARC.--A flash caused by an electric circuit ionizing a gas or vapor.

ARMATURE.--The rotating part of an electric motor or generator. The moving part of a relay or vibrator.

ATOM.--The smallest particle into which matter may be divided by chemical means.

ATTENUATION.--The reduction in the strength of a signal.

AUTOTRANSFORMER.—A transformer in which the primary and secondary are connected together in one winding.

AZIMUTH.--The angular measurement in a horizontal plane and in a clockwise direction, beginning at a point oriented to north.

BALLAST RESISTOR.—A resistor that has th characteristic of decreasing its resistanc when current flow decreases.

BATTERY.--Two or more primary or secondar cells connected together electrically. Th term does not apply to a single-cell.

BIAS.—Vacuum tube—the difference of potentia between the control grid and the cathode transistor—the difference of potential be tween the base and emitter and the base an collector; magnetic amplifier--the level o flux density in the magnetic amplifier cor under no-signal condition.

BIAS WINDING.—The winding on the core of magnetic amplifier that controls the bias

BREAKDOWN DIODE.—(See Zener diode.)

BREAKER POINTS.—Metal contacts that ope and close a circuit at timed intervals.

BRUSH.—The conducting material, usually block of carbon, bearing against the com mutator or sliprings through which th current flows in or out.

BUS BAR.—A primary power distribution poin connected to the main power source.

CAPACITOR.—Two electrodes or sets of elec trodes in the form of plates, separated fro each other by an insulating material calle the dielectric.

CASCADE.—In series, such as tuning circuit or amplifier stages used one after another

CATHODE.—The electrode in a vacuum tub which is the source of electron emission also a negative electrode.

CHOKE COIL.—A coil of low ohmic resistanc and high impedance to alternating current

CIRCUIT.—The complete path of an electri current.

CIRCUIT BREAKER.—An electromagnetic o thermal device that opens a circuit whe the current in the circuit exceeds a pre determined amount. Circuit breakers ca be reset.

CIRCULAR MIL.—An area equal to that of circle with a diameter of 0.001 inch. It i used for measuring the cross section o wires.

APPENDIX 1

STANDARD ANNEALED SOLID COPPER WIRE TABLE

(American Wire Gage -- B. and S.)

Gage number	Diameter (mils)	Cross section		Ohms per 1,000 ft.	Pounds per 1,000 ft.	Continuous current capacity (amps.)*	
		Circular mils	Square inches	25°C. (= 77°F.)		Single wire free air	Wires in conduit or bundles
0000	460.0	212,000.0	0.166	0.0500	641.0	380	225
000	410.0	168,000.0	.132	.0630	508.0	328	200
00	365.0	133,000.0	.105	.0795	403.0	283	175
0	325.0	106,000.0	.0829	.100	319.0	245	150
1	289.0	83,700.0	.0657	.126	253.0	211	125
2	258.0	66,400.0	.0521	.159	201.0	181	100
3	229.0	52,600.0	.0413	.201	159.0	-------	---------
4	204.0	41,700.0	.0328	.253	126.0	135	80
5	182.0	33,100.0	.0260	.319	100.0	-------	---------
6	162.0	26,300.0	.0206	.403	79.5	101	60
7	144.0	20,800.0	.0164	.508	63.0	-------	---------
8	128.0	16,500.0	.0130	.641	50.0	73	46
9	114.0	13,100.0	.0103	.808	39.6	-------	---------
10	102.0	10,400.0	.00815	1.02	31.4	55	33
11	91.0	8,230.0	.00647	1.28	24.9	-------	---------
12	81.0	6,530.0	.00513	1.62	19.8	41	23
13	72.0	5,180.0	.00407	2.04	15.7	-------	---------
14	64.0	4,110.0	.00323	2.58	12.4	32	17
15	57.0	3,260.0	.00256	3.25	9.86	-------	---------
16	51.0	2,580.0	.00203	4.09	7.82	22	13
17	45.0	2,050.0	.00161	5.16	6.20	-------	---------
18	40.0	1,620.0	.00128	6.51	4.92	16	10
19	36.0	1,290.0	.00101	8.21	3.90	-------	---------
20	32.0	1,020.0	.000802	10.4	3.09	11	7.5
21	28.5	810.0	.000636	13.1	2.45	-------	---------
22	25.3	642.0	.000505	16.5	1.94	-------	5
23	22.6	509.0	.000400	20.8	1.54	-------	---------
24	20.1	404.0	.000317	26.2	1.22	-------	---------
25	17.9	320.0	.000252	33.0	0.970	-------	---------
26	15.9	254.0	.000200	41.6	0.769	-------	---------
27	14.2	202.0	.000158	52.5	0.610	-------	---------
28	12.6	160.0	.000126	66.2	0.484	-------	---------
29	11.3	127.0	.0000995	83.4	0.384	-------	---------
30	10.0	101.0	.0000789	105.0	0.304	-------	---------
31	8.9	79.7	.0000626	133.0	0.241	-------	---------
32	8.0	63.2	.0000496	167.0	0.191	-------	---------
33	7.1	50.1	.0000394	211.0	0.152	-------	---------
34	6.3	39.8	.0000312	266.0	0.120	-------	---------
35	5.6	31.5	.0000248	335.0	0.0954	-------	---------
36	5.0	25.0	.0000196	423.0	0.0757	-------	---------
37	4.5	19.8	.0000156	533.0	0.0600	-------	---------
38	4.0	15.7	.0000123	673.0	0.0476	-------	---------
39	3.5	12.5	.0000098	848.0	0.0377	-------	---------
40	3.1	9.9	.0000078	1,070.0	0.0299	-------	---------

*Military Specification MIL-W-5088A

NOTE: The current carrying capacity of ALUMINUM wire is approximately 80% that of copper.

7. Detailed information on the suppression of radio noise in aircraft can be found in
   a. NavAer 16-1-521
   b. NavAer 16-1-518
   c. T.O. No. 16-1-44
   d. NavPers 10087

8. The UPM-55 pulse generator
   a. provides, displays, and measures output pulses
   b. is designed to provide stable operation of sweeps for long durations and high repetition rates
   c. can accurately measure output pulses from equipment under test
   d. does all of the above

9. The microwave oscillator, V301, used in the AN/UPM-32 is a reflex klystron which operates on the principle of velocity modulation and may be tuned
   a. mechanically only
   b. mechanically by varying the repeller plate and electrically by varying the voltages on the cavities
   c. electrically only
   d. either mechanically or electrically

10. An efficient and systematic plan of troubleshooting can best be accomplished by
   a. use of proper test equipment
   b. reference to the Handbook of Service Instructions
   c. a good understanding of the theory of operation of the equipment
   d. reference to the Handbook of Aircraft Inspection Requirements

11. The 6BN6 vacuum tube (V301, fig. 15-8)
   a. is a conventional pentode
   b. is a conventional hexode
   c. is a conventional beam power tube
   d. emits a focused beam of electrons from its cathode in a manner similar to a CRT

12. A spectrum without deep minimum points adjacent to the main lobe indicates the presence of_____ modulation.
   a. phase
   b. amplitude
   c. frequency
   d. power

13. Static discharge wicks are used to
   a. combat manmade noises in aircraft communications equipment
   b. prevent development of large static charges on an aircraft when flying through areas of precipitation
   c. overcome effects of high magnetic fields
   d. reduce the effects of atmospheric static on VHF and UHF equipment

14. The AN/UPM-32 is a portable test set de signed primarily for use with radar set operating in the frequency range of
   a. 18 cycles to 18 kc.
   b. 8,500 mc. to 10,500 mc.
   c. 8,500 to 9,400 kc.
   d. 18 kc. to 3,500 mc.

15. If a spectrum has two peaks
   a. the magnetron is probably operatir in two different modes
   b. amplitude modulation is present
   c. phase modulation is present
   d. the frequency meter resonant cavity emitting harmonics

16. Which of the following is not used for su pression of manmade radio noise?
   a. Insulated antenna system
   b. Isolation
   c. Shielding
   d. Filtering

17. Among other things, the AN/UPM-32 capable of serving as a
   a. boresighting equipment for radar se
   b. general-purpose synchroscope
   c. voltammeter
   d. range, azimuth, and elevation curre source for testing radar sets

18. The ripple frequency of a 3-phase brid rectifier connected to a 400-cycle sour is_______ c.p.s.
   a. 400
   b. 800
   c. 1,200
   d. 2,400

19. With all safety devices operating correctl what is the most likely trouble source high altitude electronic equipments?
   a. High voltage arc-over
   b. Excessive brush wear
   c. Switch contacts "welding"
   d. Waveguides exploding from exce pressure

20. Electrolytic capacitors should
   a. never be used as filters because of tl danger of dielectric breakdown
   b. always be used for noise filtering b cause they have low inductance
   c. be used where high-frequency nois are to be filtered
   d. always be used for noise filtering b cause they have high inductance

points. The major test points are assigned to critical points in circuits interconnecting assemblies or at input/output connections. These points are used to localize a trouble to a particular assembly or group. Secondary test points are generally assigned to critical points between circuits within an assembly. These points are used in localizing trouble to a particular circuit of the assembly. Minor test points are assigned to points within circuits bracketed by secondary test points. These are used to isolate the trouble to a particular stage of the circuit.

Section V of the Handbook of Service Instructions also lists in detail the removal and replacement instructions for assemblies, subassemblies, and parts which might be found faulty in the performance and trouble analysis checks. It lists the step-by-step procedure for minor repairs and adjustments necessary after the replacement of parts for the test set to meet the minimum performance standards.

Alinement

The complete procedures for alinement and adjustment of the test set are contained in section VI of the *Handbook of Service Instructions.* The control or adjustments described in the handbook need only be checked occasionally or whenever a tube or detail part is replaced in the circuitry directly associated with any given control.

Section VI lists the detailed procedures for alining the:

1. IF amplifier assembly.
2. Video amplifiers.
3. Pulse generator assembly.

It also lists in table form a complete schedule for maintenance inspections, listing the item to be checked, inspection required, and the time interval between inspections. (NOTE: The test set should be turned in to the activity's overhaul center after each 2,000 hours of operating time.)

Another important maintenance aid included in section VI is the bench test setups utilizing the test set. It includes cabling details for interconnecting the test set and the test equipment used in the minimum performance procedures discussed previously.

Section VII of the *Handbook of Service Instructions* consists of information and diagrams used in both maintenance and alinement. The diagrams will be especially useful in conjunction with the trouble analysis charts. All the test points noted in the trouble analysis charts are indicated on the schematic diagrams in this section. It also contains a complete set of waveform diagrams (photographs) which appear at the various designated test points.

QUIZ

1. The main cause of malfunctioning of electronic equipment at high altitude is
   a. lack of oxygen
   b. low temperatures
   c. lower breakdown voltage
   d. condensation

2. In order to keep carbon dust from collecting in the generator and still seat the brushes properly, you should
   a. order the proper brushes
   b. construct a simple contouring device
   c. use a special seating compound
   d. use a special liquid for cleaning

3. Spectrum-analyzer operation of the AN/UPM-32 is a plot on the CRT of
   a. time versus amplitude of the resonant cavity oscillations
   b. time versus power of the input signal
   c. time versus amplitude of the input signal
   d. frequency versus power for the input signal

4. Climatic deterioration is most prevalent in
   a. temperate zones
   b. the Arctic
   c. the Antarctic
   d. tropical zones

5. Corona conduction is best controlled by
   a. bonding
   b. felt
   c. shielding
   d. isolation

6. The DBM attenuator in the AN/UPM-32 consists of a rectangular glass vane coated with a resistive material mounted.
   a. inside the waveguide parallel to the narrow dimension wall
   b. inside the waveguide parallel to the wide dimension wall
   c. inside a choke joint of the waveguide
   d. between the frequency meter and the klystron, V301

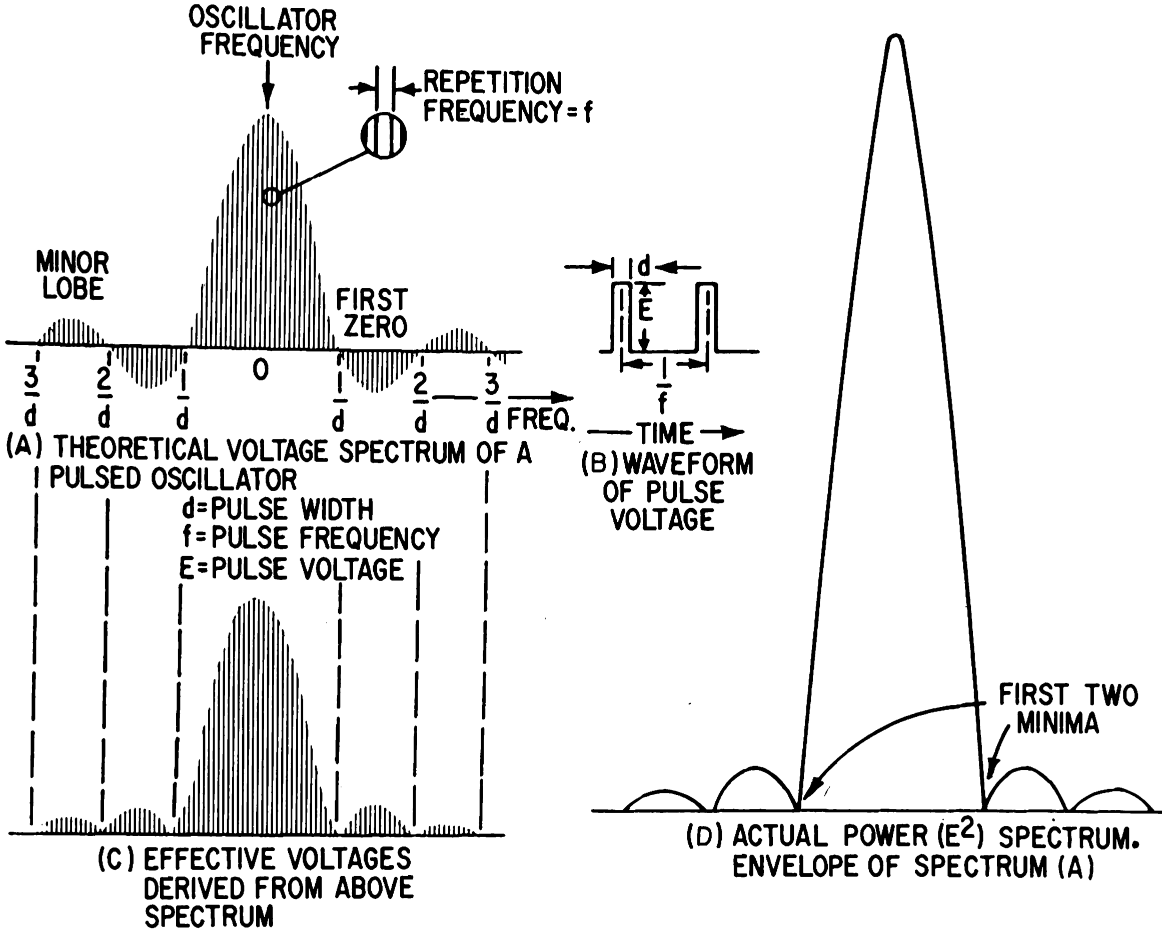

OSCILLATOR FREQUENCY
REPETITION FREQUENCY = f
MINOR LOBE
FIRST ZERO
3/d
2/d
1/d
0
1/d
2/d
3/d
FREQ.
(A) THEORETICAL VOLTAGE SPECTRUM OF A PULSED OSCILLATOR
d = PULSE WIDTH
f = PULSE FREQUENCY
E = PULSE VOLTAGE
d
E
1/f
TIME
(B) WAVEFORM OF PULSE VOLTAGE
FIRST TWO MINIMA
(C) EFFECTIVE VOLTAGES DERIVED FROM ABOVE SPECTRUM
(D) ACTUAL POWER (E²) SPECTRUM. ENVELOPE OF SPECTRUM (A)

Figure 15-25. —Conversion of a voltage spectrum to a power spectrum.

8. The frequency difference between two peaks indicates the amount of frequency pulling. The height indicates the relative power at the frequency of each peak.

Maintenance

The information presented in this section is intended to aid the Aviation Electronics Technician in the prevention and correction of troubles in the Radar Test Set AN/UPM-32.

A thorough knowledge of the material covered thus far, as to physical makeup, characteristics, capabilities, limitations, and general theory of operation, will greatly facilitate maintenance procedures.

The technician should bear in mind that the operation of this equipment involves high voltages which are dangerous to life. Maintenance personnel must observe safety regulations at a times.

No maintenance should be attempted on th equipment without the test set's *Handbook o Service Instructions* for ready reference. Section V of this handbook lists in table form th minimum performance standards of the test se It includes the purpose of the check, procedur normal indications, and a list of possible cause of abnormal indications. Section V of the *Hanc book of Service Instructions* also lists a ste by-step procedure for isolation of a trouble a faulty circuit, group of circuits, or part. system of symbols is used in the check char for indicating in the equipment where test co nections are made for measuring or observi electrical data. The symbols are divided in three classes: major, secondary, and minor te

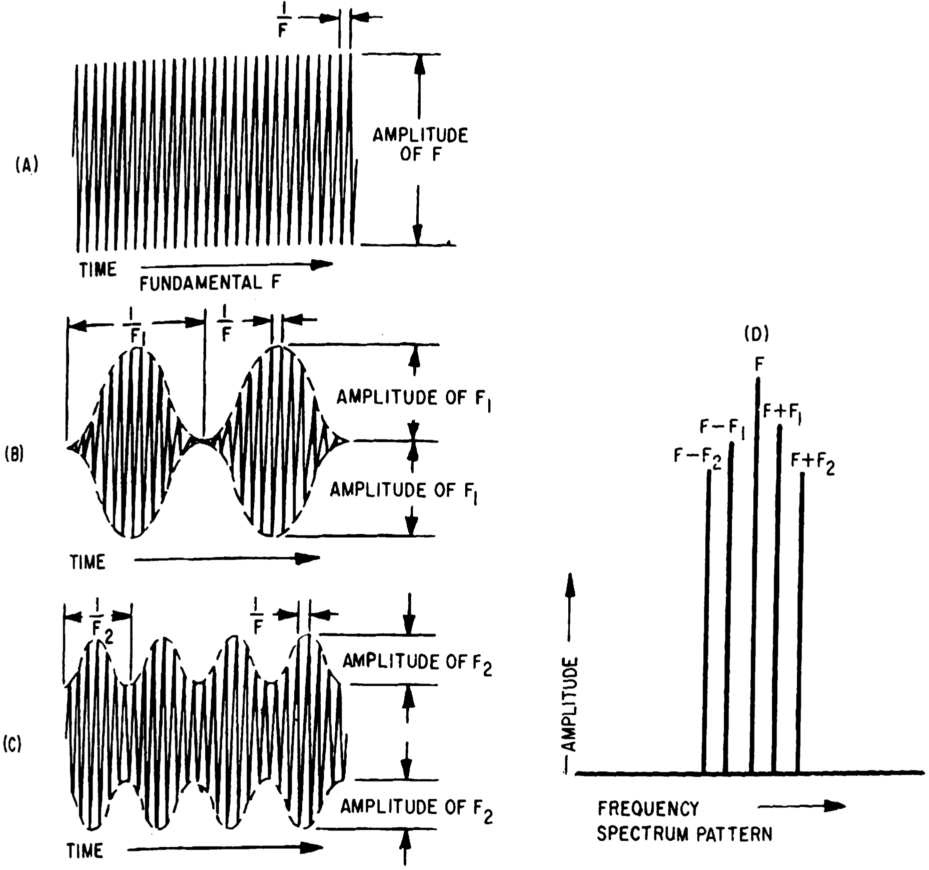


Figure 15-24. —Formation of a spectrum.

a visual examination of a radar spectrum valuable in three general ways:

1. In checking for stability of a magnetron.
2. In tuning a radar system so that most of output power is within the frequency range the receiver band-pass response.
3. In analyzing radar system outputs to de- mine causes of poor spectra.

It is important to note that the shape of the ectrum of a pulsed signal depends chiefly upon characteristics of the signal. They are:

1. The modulation envelope of the pulse.
2. The shifting of the oscillator frequency ring the pulse.

In general the following statements apply in analysis of a spectrum:

1. The ideal spectrum is achieved when the lse is truly rectangular and there is no fre- ency modulation.
2. The distance between the first two minima of an ideal spectrum is a measure of the pulse width of the signal.
3. The distance between the first two minima should not be much greater than the receiver bandwidth, because by far the greatest amount of power is in the center lobe of an ideal spectrum.
4. An effect of frequency modulation is to increase the amplitude of the side lobes.
5. A large number of side lobes indicates the presence of amplitude modulation.
6. A spectrum without deep minimum points adjacent to the main lobe indicates the presence of frequency modulation.
7. If the spectrum has two peaks, the magnetron is operating in two modes or else is being pulled in frequency by some external force, such as a poorly matched rotating scanner or fluctuating voltages.

45°–59.9°

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
45	sin cos tan	0.7071 0.7071 1.0000	0.7083 0.7059 1.0035	0.7096 0.7046 1.0070	0.7108 0.7034 1.0105	0.7120 0.7022 1.0141	0.7133 0.7009 1.0176	0.7145 0.6997 1.0212	0.7157 0.6984 1.0247	0.7169 0.6972 1.0283	0.7181 0.6959 1.0319
46	sin cos tan	0.7193 0.6947 1.0355	0.7206 0.6934 1.0392	0.7218 0.6921 1.0428	0.7230 0.6909 1.0464	0.7242 0.6896 1.0501	0.7254 0.6884 1.0538	0.7266 0.6871 1.0575	0.7278 0.6858 1.0612	0.7290 0.6845 1.0649	0.7302 0.6833 1.0686
47	sin cos tan	0.7314 0.6820 1.0724	0.7325 0.6807 1.0761	0.7337 0.6794 1.0799	0.7349 0.6782 1.0837	0.7361 0.6769 1.0875	0.7373 0.6756 1.0913	0.7385 0.6743 1.0951	0.7396 0.6730 1.0990	0.7408 0.6717 1.1028	0.7420 0.6704 1.1067
48	sin cos tan	0.7431 0.6691 1.1106	0.7443 0.6678 1.1145	0.7455 0.6665 1.1184	0.7466 0.6652 1.1224	0.7478 0.6639 1.1263	0.7490 0.6626 1.1303	0.7501 0.6613 1.1343	0.7513 0.6600 1.1383	0.7524 0.6587 1.1423	0.7536 0.6574 1.1463
49	sin cos tan	0.7547 0.6561 1.1504	0.7559 0.6547 1.1544	0.7570 0.6534 1.1585	0.7581 0.6521 1.1626	0.7593 0.6508 1.1667	0.7604 0.6494 1.1708	0.7615 0.6481 1.1750	0.7627 0.6468 1.1792	0.7638 0.6455 1.1833	0.7649 0.6441 1.1875
50	sin cos tan	0.7660 0.6428 1.1918	0.7672 0.6414 1.1960	0.7683 0.6401 1.2002	0.7694 0.6388 1.2045	0.7705 0.6374 1.2088	0.7716 0.6361 1.2131	0.7727 0.6347 1.2174	0.7738 0.6334 1.2218	0.7749 0.6320 1.2261	0.7760 0.6307 1.2305
51	sin cos tan	0.7771 0.6293 1.2349	0.7782 0.6280 1.2393	0.7793 0.6266 1.2437	0.7804 0.6252 1.2482	0.7815 0.6239 1.2527	0.7826 0.6225 1.2572	0.7837 0.6211 1.2617	0.7848 0.6198 1.2662	0.7859 0.6184 1.2708	0.7869 0.6170 1.2753
52	sin cos tan	0.7880 0.6157 1.2799	0.7891 0.6143 1.2846	0.7902 0.6129 1.2892	0.7912 0.6115 1.2938	0.7923 0.6101 1.2985	0.7934 0.6088 1.3032	0.7944 0.6074 1.3079	0.7955 0.6060 1.3127	0.7965 0.6046 1.3175	0.7976 0.6032 1.3222
53	sin cos tan	0.7986 0.6018 1.3270	0.7997 0.6004 1.3319	0.8007 0.5990 1.3367	0.8018 0.5976 1.3416	0.8028 0.5962 1.3465	0.8039 0.5948 1.3514	0.8049 0.5934 1.3564	0.8059 0.5920 1.3613	0.8070 0.5906 1.3663	0.8080 0.5892 1.3713
54	sin cos tan	0.8090 0.5878 1.3764	0.8100 0.5864 1.3814	0.8111 0.5850 1.3865	0.8121 0.5835 1.3916	0.8131 0.5821 1.3968	0.8141 0.5807 1.4019	0.8151 0.5793 1.4071	0.8161 0.5779 1.4124	0.8171 0.5764 1.4176	0.8181 0.5750 1.4229
55	sin cos tan	0.8192 0.5736 1.4281	0.8202 0.5721 1.4335	0.8211 0.5707 1.4388	0.8221 0.5693 1.4442	0.8231 0.5678 1.4496	0.8241 0.5664 1.4550	0.8251 0.5650 1.4605	0.8261 0.5635 1.4659	0.8271 0.5621 1.4715	0.8281 0.5606 1.4770
56	sin cos tan	0.8290 0.5592 1.4826	0.8300 0.5577 1.4882	0.8310 0.5563 1.4938	0.8320 0.5548 1.4994	0.8329 0.5534 1.5051	0.8339 0.5519 1.5108	0.8348 0.5505 1.5166	0.8358 0.5490 1.5224	0.8368 0.5476 1.5282	0.8377 0.5461 1.5340
57	sin cos tan	0.8387 0.5446 1.5399	0.8396 0.5432 1.5458	0.8406 0.5417 1.5517	0.8415 0.5402 1.5577	0.8425 0.5388 1.5637	0.8434 0.5373 1.5697	0.8443 0.5358 1.5757	0.8453 0.5344 1.5818	0.8462 0.5329 1.5880	0.8471 0.5314 1.5941
58	sin cos tan	0.8480 0.5299 1.6003	0.8490 0.5284 1.6066	0.8499 0.5270 1.6128	0.8508 0.5255 1.6191	0.8517 0.5240 1.6255	0.8526 0.5225 1.6319	0.8536 0.5210 1.6383	0.8545 0.5195 1.6447	0.8554 0.5180 1.6512	0.8563 0.5165 1.6577
59	sin cos tan	0.8572 0.5150 1.6643	0.8581 0.5135 1.6709	0.8590 0.5120 1.6775	0.8590 0.5105 1.6842	0.8607 0.5090 1.6909	0.8616 0.5075 1.6977	0.8625 0.5060 1.7045	0.8634 0.5045 1.7113	0.8643 0.5030 1.7182	0.8652 0.5015 1.7251
Degs.	Function	0′	6′	12′	18′	24′	30′	36′	42′	43′	54′

60°–74.9°

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
60	sin	0.8660	0.8669	0.8678	0.8686	0.8695	0.8704	0.8712	0.8721	0.8729	0.8738
	cos	0.5000	0.4985	0.4970	0.4955	0.4939	0.4924	0.4909	0.4894	0.4879	0.4863
	tan	1.7321	1.7391	1.7461	1.7532	1.7603	1.7675	1.7747	1.7820	1.7893	1.7966
61	sin	0.8746	0.8755	0.8763	0.8771	0.8780	0.8788	0.8796	0.8805	0.8813	0.8821
	cos	0.4848	0.4833	0.4818	0.4802	0.4787	0.4772	0.4756	0.4741	0.4726	0.4710
	tan	1.8040	1.8115	1.8190	1.8265	1.8341	1.8418	1.8495	1.8572	1.8650	1.8728
62	sin	0.8829	0.8838	0.8846	0.8854	0.8862	0.8870	0.8878	0.8886	0.8894	0.8902
	cos	0.4695	0.4679	0.4664	0.4648	0.4633	0.4617	0.4602	0.4586	0.4571	0.4555
	tan	1.8807	1.8887	1.8967	1.9047	1.9128	1.9210	1.9292	1.9375	1.9458	1.9542
63	sin	0.8910	0.8918	0.8926	0.8934	0.8942	0.8949	0.8957	0.8965	0.8973	0.8980
	cos	0.4540	0.4524	0.4509	0.4493	0.4478	0.4462	0.4446	0.4431	0.4415	0.4399
	tan	1.9626	1.9711	1.9797	1.9883	1.9970	2.0057	2.0145	2.0233	2.0323	2.0413
64	sin	0.8988	0.8996	0.9003	0.9011	0.9018	0.9026	0.9033	0.9041	0.9048	0.9056
	cos	0.4384	0.4368	0.4352	0.4337	0.4321	0.4305	0.4289	0.4274	0.4258	0.4242
	tan	2.0503	2.0594	2.0686	2.0778	2.0872	2.0965	2.1060	2.1155	2.1251	2.1348
65	sin	0.9063	0.9070	0.9078	0.9085	0.9092	0.9100	0.9107	0.9114	0.9121	0.9128
	cos	0.4226	0.4210	0.4195	0.4179	0.4163	0.4147	0.4131	0.4115	0.4099	0.4083
	tan	2.1445	2.1543	2.1642	2.1742	2.1842	2.1943	2.2045	2.2148	2.2251	2.2355
66	sin	0.9135	0.9143	0.9150	0.9157	0.9164	0.9171	0.9178	0.9184	0.9191	0.9198
	cos	0.4067	0.4051	0.4035	0.4019	0.4003	0.3987	0.3971	0.3955	0.3939	0.3923
	tan	2.2460	2.2566	2.2673	2.2781	2.2889	2.2998	2.3109	2.3220	2.3332	2.3445
67	sin	0.9205	0.9212	0.9219	0.9225	0.9232	0.9239	0.9245	0.9252	0.9259	0.9265
	cos	0.3907	0.3891	0.3875	0.3859	0.3843	0.3827	0.3811	0.3795	0.3778	0.3762
	tan	2.3559	2.3673	2.3789	2.3906	2.4023	2.4142	2.4262	2.4383	2.4504	2.4627
68	sin	0.9272	0.9278	0.9285	0.9291	0.9298	0.9304	0.9311	0.9317	0.9323	0.9330
	cos	0.3746	0.3730	0.3714	0.3697	0.3681	0.3665	0.3649	0.3633	0.3616	0.3600
	tan	2.4751	2.4876	2.5002	2.5129	2.5257	2.5386	2.5517	2.5649	2.5782	2.5916
69	sin	0.9336	0.9342	0.9348	0.9354	0.9361	0.9367	0.9373	0.9379	0.9385	0.9391
	cos	0.3584	0.3567	0.3551	0.3535	0.3518	0.3502	0.3486	0.3469	0.3453	0.3437
	tan	2.6051	2.6187	2.6325	2.6464	2.6605	2.6746	2.6889	2.7034	2.7179	2.7326
70	sin	0.9397	0.9403	0.9409	0.9415	0.9421	0.9426	0.9432	0.9438	0.9444	0.9449
	cos	0.3420	0.3404	0.3387	0.3371	0.3355	0.3338	0.3322	0.3305	0.3289	0.3272
	tan	2.7475	2.7625	2.7776	2.7929	2.8083	2.8239	2.8397	2.8556	2.8716	2.8878
71	sin	0.9455	0.9461	0.9466	0.9472	0.9478	0.9483	0.9489	0.9494	0.9500	0.9505
	cos	0.3256	0.3239	0.3223	0.3206	0.3190	0.3173	0.3156	0.3140	0.3123	0.3107
	tan	2.9042	2.9208	2.9375	2.9544	2.9714	2.9887	3.0061	3.0237	3.0415	3.0595
72	sin	0.9511	0.9516	0.9521	0.9527	0.9532	0.9537	0.9542	0.9548	0.9553	0.9558
	cos	0.3090	0.3074	0.3057	0.3040	0.3024	0.3007	0.2990	0.2974	0.2957	0.2940
	tan	3.0777	3.0961	3.1146	3.1334	3.1524	3.1716	3.1910	3.2106	3.2305	3.2506
73	sin	0.9563	0.9568	0.9573	0.9578	0.9583	0.9588	0.9593	0.9598	0.9603	0.9608
	cos	0.2924	0.2907	0.2890	0.2874	0.2857	0.2840	0.2823	0.2807	0.2790	0.2773
	tan	3.2709	3.2914	3.3122	3.3332	3.3544	3.3759	3.3977	3.4197	3.4420	3.4646
74	sin	0.9613	0.9617	0.9622	0.9627	0.9632	0.9636	0.9641	0.9646	0.9650	0.9655
	cos	0.2756	0.2740	0.2723	0.2706	0.2689	0.2672	0.2656	0.2639	0.2622	0.2605
	tan	3.4874	3.5105	3.5339	3.5576	3.5816	3.6059	3.6305	3.6554	3.6806	3.7062
Degs.	Function	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′

75°–89.9°

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
75	sin	0.9659	0.9664	0.9668	0.9673	0.9677	0.9681	0.9686	0.9690	0.9694	0.9699
	cos	0.2588	0.2571	0.2554	0.2538	0.2521	0.2504	0.2487	0.2470	0.2453	0.2436
	tan	3.7321	3.7583	3.7848	3.8118	3.8391	3.8667	3.8947	3.9232	3.9520	3.9812
76	sin	0.9703	0.9707	0.9711	0.9715	0.9720	0.9724	0.9728	0.9732	0.9736	0.9740
	cos	0.2419	0.2402	0.2385	0.2368	0.2351	0.2334	0.2317	0.2300	0.2284	0.2267
	tan	4.0108	4.0408	4.0713	4.1022	4.1335	4.1653	4.1976	4.2303	4.2635	4.2972
77	sin	0.9744	0.9748	0.9751	0.9755	0.9759	0.9763	0.9767	0.9770	0.9774	0.9778
	cos	0.2250	0.2232	0.2215	0.2198	0.2181	0.2164	0.2147	0.2130	0.2113	0.2096
	tan	4.3315	4.3602	4.4015	4.4374	4.4737	4.5107	4.5483	4.5864	4.6252	4.6646
78	sin	0.9781	0.9785	0.9789	0.9792	0.9796	0.9799	0.9803	0.9806	0.9810	0.9813
	cos	0.2079	0.2062	0.2045	0.2028	0.2011	0.1994	0.1977	0.1959	0.1942	0.1925
	tan	4.7046	4.7453	4.7867	4.8288	4.8716	4.9152	4.9594	5.0045	5.0504	5.0970
79	sin	0.9816	0.9820	0.9823	0.9826	0.9829	0.9833	0.9836	0.9839	0.9842	0.9845
	cos	0.1908	0.1891	0.1874	0.1857	0.1840	0.1822	0.1805	0.1788	0.1771	0.1754
	tan	5.1446	5.1929	5.2422	5.2924	5.3435	5.3955	5.4486	5.5026	5.5578	5.6140
80	sin	0.9848	0.9851	0.9854	0.9857	0.9860	0.9863	0.9866	0.9869	0.9871	0.9874
	cos	0.1736	0.1719	0.1702	0.1685	0.1668	0.1650	0.1633	0.1616	0.1599	0.1582
	tan	5.6713	5.7297	5.7894	5.8502	5.9124	5.9758	6.0405	6.1066	6.1742	6.2432
81	sin	0.9877	0.9880	0.9882	0.9885	0.9888	0.9890	0.9893	0.9895	0.9898	0.9900
	cos	0.1564	0.1547	0.1530	0.1513	0.1495	0.1478	0.1461	0.1444	0.1426	0.1409
	tan	6.3138	6.3859	6.4596	6.5350	6.6122	6.6912	6.7720	6.8548	6.9395	7.0264
82	sin	0.9903	0.9905	0.9907	0.9910	0.9912	0.9914	0.9917	0.9919	0.9921	0.9923
	cos	0.1392	0.1374	0.1357	0.1340	0.1323	0.1305	0.1288	0.1271	0.1253	0.1236
	tan	7.1154	7.2066	7.3002	7.3962	7.4947	7.5958	7.6996	7.8062	7.9158	8.0285
83	sin	0.9925	0.9928	0.9930	0.9932	0.9934	0.9936	0.9938	0.9940	0.9942	0.9943
	cos	0.1219	0.1201	0.1184	0.1167	0.1149	0.1132	0.1115	0.1097	0.1080	0.1063
	tan	8.1443	8.2636	8.3863	8.5126	8.6427	8.7769	8.9152	9.0579	9.2052	9.3572
84	sin	0.9945	0.9947	0.9949	0.9951	0.9952	0.9954	0.9956	0.9957	0.9959	0.9960
	cos	0.1045	0.1028	0.1011	0.0993	0.0976	0.0958	0.0941	0.0924	0.0906	0.0889
	tan	9.5144	9.6768	9.8448	10.02	10.20	10.39	10.58	10.78	10.99	11.20
85	sin	0.9962	0.9963	0.9965	0.9966	0.9968	0.9969	0.9971	0.9972	0.9973	0.9974
	cos	0.0872	0.0854	0.0837	0.0819	0.0802	0.0785	0.0767	0.0750	0.0732	0.0715
	tan	11.43	11.66	11.91	12.16	12.43	12.71	13.00	13.30	13.62	13.95
86	sin	0.9976	0.9977	0.9978	0.9979	0.9980	0.9981	0.9982	0.9983	0.9984	0.9985
	cos	0.0698	0.0680	0.0663	0.0645	0.0628	0.0610	0.0593	0.0576	0.0558	0.0541
	tan	14.30	14.67	15.06	15.46	15.89	16.35	16.83	17.34	17.89	18.46
87	sin	0.9986	0.9987	0.9988	0.9989	0.9990	0.9990	0.9991	0.9992	0.9993	0.9993
	cos	0.0523	0.0506	0.0488	0.0471	0.0454	0.0436	0.0419	0.0401	0.0384	0.0366
	tan	19.08	19.74	20.45	21.20	22.02	22.90	23.86	24.90	26.03	27.27
88	sin	0.9994	0.9995	0.9995	0.9996	0.9996	0.9997	0.9997	0.9997	0.9998	0.9998
	cos	0.0349	0.0332	0.0314	0.0297	0.0279	0.0262	0.0244	0.0227	0.0209	0.0192
	tan	28.64	30.14	31.82	33.69	35.80	38.19	40.92	44.07	47.74	52.08
89	sin	0.9998	0.9999	0.9999	0.9999	0.9999	1.000	1.000	1.000	1.000	1.000
	cos	0.0175	0.0157	0.0140	0.0122	0.0106	0.0087	0.0070	0.0052	0.0035	0.0017
	tan	57.29	63.66	71.62	81.85	95.49	114.6	143.2	191.0	286.5	573.0
Degs.	Function	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′

APPENDIX VIII

COMMON LOGARITHMS OF NUMBERS

No.	0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396
No.	0	1	2	3	4	5	6	7	8	9

No.	0	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996
No.	0	1	2	3	4	5	6	7	8	9

APPENDIX IX

ANSWERS TO QUIZZES

Chapter 1

DUTIES AND RESPONSIBILITIES

1. a.
2. d.
3. d.
4. c.
5. b.
6. b.
7. d.
8. c.
9. c.
10. d.
11. a.
12. d.
13. a.
14. a.
15. a.

Chapter 2

SUPPLY AND PUBLICATIONS

1. a.
2. a.
3. c.
4. a.
5. b.
6. d.
7. b.
8. c.
9. c.
10. b.
11. d.
12. c.
13. b.
14. a.
15. d.
16. c.
17. a.
18. a.
19. c.
20. d.

Chapter 3

RC AND RL NETWORKS

1. d.
2. c.
3. b.
4. a.
5. b.
6. a.
7. c.
8. d.
9. b.
10. c.
11. b.
12. b.
13. a.
14. a.
15. a.
16. b.
17. b.
18. b.
19. a.
20. d.
21. d.

Chapter 4

SPECIAL CIRCUITS

1. d.
2. b.
3. c.
4. a.
5. c.
6. d.
7. c.
8. b.
9. b.
10. d.
11. d.
12. d.
13. a.
14. a.
15. b.
16. d.
17. c.
18. b.
19. b.
20. a.
21. d.
22. d.
23. b.
24. c.

Chapter 5

SPECIAL CIRCUITS – CONTINUED

1. b.
2. b.
3. c.
4. d.
5. c.
6. b.
7. a.
8. b.
9. a.
10. a.
11. c.
12. d.
13. d.
14. c.
15. c.
16. b.
17. b.
18. c.
19. d.
20. c.
21. a.
22. d.

Chapter 6

PROPAGATION OF RADIO WAVES

1. c.
2. c.
3. a.
4. b.
5. c.
6. b.
7. a.
8. c.
9. c.
10. a.
11. b.
12. d.
13. b.
14. a.
15. b.
16. b.
17. d.
18. c.
19. a.
20. b.
21. a.
22. d.
23. a.

Chapter 7

WAVEGUIDES AND CAVITY RESONATORS

1. a.
2. b.
3. b.
4. d.
5. a.
6. b.
7. b.
8. b.
9. b.
10. b.
11. b.
12. a.
13. c.
14. d.
15. a.
16. d.
17. c.
18. c.

Chapter 8

UHF AND MICROWAVE TECHNIQUES

1. a.
2. a.
3. d.
4. d.
5. a.
6. b.
7. b.
8. c.
9. d.
10. a.
11. a.
12. b.
13. a.
14. c.
15. d.
16. b.
17. a.
18. c.
19. b.
20. c.
21. c.
22. a.
23. a.

Chapter 9

UHF AND MICROWAVE ANTENNAS

1. a.
2. d.
3. c.
4. a.
5. d.
6. b.
7. b.
8. b.
9. a.
10. c.
11. c.
12. c.
13. c.
14. b.
15. b.
16. a.
17. c.
18. b.
19. c.
20. b.
21. a.
22. a.
23. a.
24. d.

Chapter 10

SERVOMECHANISMS

1. d.
2. a.
3. a.
4. d.
5. c.
6. a.
7. b.
8. b.
9. d.
10. c.
11. c.
12. d.
13. a.
14. d.
15. a.
16. b.
17. d.
18. c.
19. d.
20. b.
21. a.
22. b.
23. b.

Chapter 11

TRANSISTOR CIRCUITRY

1. c.
2. b.
3. d.
4. d.
5. a.
6. b.
7. c.
8. c.
9. a.
10. b.
11. a.
12. d.
13. c.
14. c.
15. d.
16. a.
17. b.
18. a.
19. c.
20. d.
21. b.
22. b.
23. c.
24. a.
25. b.

Chapter 12

PRINCIPLES OF TELEVISION

1. a.
2. b.
3. d.
4. d.
5. d.
6. c.
7. a.
8. c.
9. c.
10. d.
11. c.
12. a.
13. b.
14. c.
15. b.
16. b.
17. a.
18. d.
19. c.
20. d.

Chapter 13

DIGITAL COMPUTERS

1. b.
2. a.
3. b.
4. c.
5. c.
6. a.
7. b.
8. a.
9. d.
10. a.
11. c.
12. c.
13. a.
14. d.
15. c.
16. a.
17. a.
18. c.
19. a.
20. a.

Chapter 14

ELECTRONIC EQUIPMENT AND RELATED TEST EQUIPMENT

1. c.
2. a.
3. c.
4. b.
5. c.
6. c.
7. d.
8. c.
9. b.
10. c.
11. b.
12. a.
13. a.
14. c.
15. d.
16. d.
17. b.
18. b.
19. a.
20. b.
21. c.

Chapter 15

TEST EQUIPMENT AND MAINTENANCE TECHNIQUES

1. c.
2. b.
3. d.
4. d.
5. a.
6. a.
7. a.
8. d.
9. d.
10. a.
11. d.
12. c.
13. b.
14. b.
15. a.
16. a.
17. b.
18. d.
19. b.
20. a.

APPENDIX X

QUALIFICATIONS FOR ADVANCEMENT IN RATING

AVIATION ELECTRONICS TECHNICIAN (AT)

(Extracted from NavPers 18068 (Revised) thru Change 16)

Rating Code No. 6300

General Rating (applicable to PO2, PO1 and CPO)

Scope

Aviation Electronics Technicians: Inspect and maintain aviation electronic equipment, including: detection, reconnaissance, identification, communication, navigation, display, and special purpose equipment; sonar and sonobuoy equipment; target drone and pilotless aircraft equipment; and related equipment and test equipment; and operate airborne CIC equipment.

Service Ratings (applicable to PO3 only)

Scopes

AVIATION ELECTRONICS TECHNICIAN N (Radio and Radio Navigation Equipment) . . . . ATN

Inspect and maintain aviation electronic identification, radio communication, and radio navigation equipment, including: radio transmitting, receiving, relaying, and direction finding equipment; radio and radar altimeters; electronic interrogating and transponding equipment; distance and time difference measuring equipment; and related equipment and test equipment.

AVIATION ELECTRONICS TECHNICIAN R (Radar and Radar Navigation Equipment) . . . . ATR

Inspect and maintain aviation radar and electronic identification equipment, including: radar; radar display and relay equipment; electronic interrogating and transponding equipment; and related equipment and test equipment.

AVIATION ELECTRONICS TECHNICIAN S (Antisubmarine Warfare Equipment) . . . . ATS

Inspect and maintain aviation antisubmarine warfare and electronic countermeasures (ECM) equipment, including: sonar and sonobuoy equipment; magnetic anomaly detection (MAD) equipment; electromagnetic radiation detecting and analyzing equipment; and related equipment and test equipment.

AVIATION ELECTRONICS TECHNICIAN W (Airborne CIC Operator) ATW

Operate airborne CIC equipment, including: radar, remote radar indicators, navigation computers, and CIC voice communications equipment; maintain status boards and plots; verify aircraft track and perform dead-reckoning navigation; detect and interpret radar targets and disseminate information; and inspect and maintain aviation radar and related electronic equipment.

Path of Advancement to Limited Duty Officer

Aviation Electronics Technicians advance to Limited Duty Officers, Aviation Electronics.

Navy Enlisted Classification Codes

See the Manual of Navy Enlisted Classifications, NAVPERS 15105B.

Qualifications for Advancement in Rating

1. Qualifications for advancement to a higher rate include qualifications of lower rate or rates in addition to those stated for the higher rate. Qualifications for advancement from a Service Rating to the General Rating include those of the other Service Ratings except for Airborne CIC Operation and Airborne CIC Navigation functions of the ATW.
2. Practical factors will be completed before recommendation for participation in the advancement examinations. (Bureau of Naval Personnel Manual, NAVPERS 15791A, Articles B-2326 and C-7201.)
3. Knowledge factors and knowledge aspects of practical factors will form the basis for questions in the written advancement examinations.
4. Practical factors for the Aviation Electronics Technician rating are applicable to the aircraft and equipment assigned or available.
5. To qualify for initial entrance into the Service Rating of Aviation Electronics Technician W (ATW), personnel must have met the physical requirements set forth in the Manual of the Medical Department for Combat Aircrewman and be a volunteer for duty involving flying.

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
A. SAFETY					
1.0 Practical Factors					
1. Observe safety precautions in making adjustments and measurements on energized electrical and electronic equipment.	3	3	3	3	--
2. Observe safety precautions in working with de-energized equipment to eliminate hazards of residual charges	3	3	3	3	--
3. Observe safety precautions in handling, stowing, and disposing of radioactive, cathode ray, and fluorescent tubes	3	3	3	3	--

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
1.0 Practical Factors - Continued					
4. Observe safety precautions in operating radio transmitters in aircraft and in energizing and directing radar antennas	3	3	3	3	--
5. Interpret directives and instructions on safety precautions to identify those applicable to electronic work areas and equipment; establish safeguards, procedures, and standards to insure compliance by personnel supervised. . .	--	--	--	--	C
6. Inspect work areas, tools, and equipment to detect potentially hazardous and unsafe conditions and take appropriate corrective action.	--	--	--	--	C
7. Organize and administer a program of safety instruction applicable to aviation electronic equipment and facilities.	--	--	--	--	C
2.0 Knowledge Factors					
None.					
B. AIRCRAFT ELECTRONICS LINE AND HANGAR MAINTENANCE					
1.0 Practical Factors					
1. Select, use, and care for common hand tools	3	3	3	3	--
2. Remove and install units of aircraft electronic systems	3	3	3	3	--
3. Make tests for short circuits, grounds, and continuity of interconnecting cables between units of electronic equipment	3	3	3	3	--
4. Clean, lubricate, and service aircraft electronic equipment . .	3	3	3	3	--
5. Check aircraft electronic equipment for proper pressurization; correct for leaks	3	3	3	3	--
6. Make entries in inspection forms, work orders, and failure reports	3	3	3	3	--
7. Perform daily and preflight inspections of aircraft electronic equipment for security of mounting and evidence of damage. . . .	3	3	3	3	--
8. Verify discrepancies in aircraft electronic equipment.	--	--	--	--	2
9. Isolate equipment malfunctions to defective units	--	--	--	--	2
10. Perform intermediate and major aircraft electronics inspections.	--	--	--	--	2

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
1.0 Practical Factors - Continued					
11. Perform operational tests of aircraft electronic equipment	--	--	--	--	2
12. Make qualitative performance tests of aircraft electronic systems.	--	--	--	--	1
13. Supervise and direct electronics line and hangar maintenance; inspect completed work	--	--	--	--	1
14. Debrief flight crews and evaluate reported discrepancies	--	--	--	--	1
15. Analyze reports of discrepancies and malfunctions in aircraft electronic systems and determine corrective action.	--	--	--	--	C
16. Evaluate performance of overhauled, modified, or newly installed aircraft electronic equipment.	--	--	--	--	C
2.0 Knowledge Factors					
1. Cable, wire, and connector identication and marking systems	3	3	3	3	--
2. Types and characteristics of safety wire, bonding, shock mounts, and metal fasteners. . . .	3	3	3	3	--
3. Types and applications of electrical circuit protective devices .	3	3	3	3	--
4. Types and applications of corrosion prevention, preservation, and moisture protecting materials used in maintenance of aircraft electronic equipment.	3	3	3	3	--
5. Requirements for auxiliary ground cooling of aircraft electronic equipment	--	--	--	--	2
C. AIRCRAFT ELECTRONICS SHOP PRACTICES					
1.0 Practical Factors					
1. Clean commutators and slip ring assemblies and replace burshes.	3	3	3	3	--
2. Use circuit and signal tracing techniques to locate defective parts within a circuit.	3	3	3	3	--
3. Make point-to-point voltage and resistance measurements. . . .	3	3	3	3	--
4. Test, select, and replace circuit parts, including electron tubes .	3	3	3	3	--
5. Remove, install, mechanically align, and electrically zero synchros	3	3	3	3	--
6. Select proper wire and fabricate aircraft electronic equipment interconnecting cables	--	--	--	--	2

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
1.0 Practical Factors - Continued					
7. Analyze operation of units in aircraft electronic equipment and isolate malfunctions to a defective circuit	--	--	--	--	2
8. Perform waveform analysis . . .	--	--	--	--	2
9. Make phase, balance, and feedback adjustments to servo amplifiers.	--	--	--	--	2
10. Adjust and align parts or circuitry in units, assemblies, or subassemblies to conform with allowable limits	--	--	--	--	2
11. Supervise the incorporation of aircraft changes involving aircraft electronic equipment	--	--	--	--	1
12. Inspect completed repairs to aircraft electronic equipment	--	--	--	--	1
13. Inspect installation and evaluate operation of repaired or newly installed parts and components .	--	--	--	--	1
14. Analyze discrepancy trends, determine deficiencies, and develop inspection procedures	--	--	--	--	C
15. Supervise the technical maintenance effort and evaluate procedures.	--	--	--	--	C
16. Screen defective exchangeable components for feasibility of local repair	--	--	--	--	C
17. Review and evaluate completed inspection forms, work orders, and failure and discrepancy reports	--	--	--	--	C
2.0 Knowledge Factors					
1. Soldering material and techniques used in maintenance of aircraft electronic equipment.	3	3	3	3	--
2. Systems of nomenclature employed to identify naval aviation electronics systems, components, and material	3	3	3	3	--
3. Methods of troubleshooting electronic equipment and their applications	--	--	--	--	2
4. Procedures for repairing printed circuits and techniques for testing transistor circuits	--	--	--	--	1
5. Sources of electrical noise interference and methods of control . .	--	--	--	--	C
6. Effects of environmental conditions upon operation of electronic and electrical equipment	--	--	--	--	C

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
D. AIRCRAFT NAVIGATION EQUIPMENT MAINTENANCE					
1.0 Practical Factors					
1. Perform routine preventive maintenance, preliminary troubleshooting, and minor repair on aircraft navigation equipment . .	3	--	--	--	--
2. Adjust and calibrate loran equipment.	3	--	--	--	--
3. Set compensation of ADF loop antennas	3	--	--	--	--
4. Make ground checks of electronic altimeters using a delay line. . .	3	--	--	--	--
5. Use portable beacon simulator to test operation of TACAN equipment.	3	--	--	--	--
6. Perform flag sensitivity adjustments on omnirange receivers .	3	--	--	--	--
7. Measure and adjust low voltage power supplies	3	--	--	--	--
8. Bench test and align ADF equipment.	--	--	--	--	2
9. Bench test and calibrate radio and radar altimeters	--	--	--	--	2
10. Bench test and align TACAN . . .	--	--	--	--	2
11. Repair and adjust automatic channel selecting and automatic tuning assemblies	--	--	--	--	1
12. Test and adjust TACAN beacon simulator	--	--	--	--	1
2.0 Knowledge Factors					
1. General characteristics of loran .	3	--	--	--	--
2. General characteristics of ADF .	3	--	--	--	--
3. General characteristics of TACAN.	--	--	--	--	2
4. Procedures for plotting deviation curves for aircraft ADF configuration.	--	--	--	--	1
E. AIRCRAFT COMMUNICATIONS EQUIPMENT MAINTENANCE					
1.0 Practical Factors					
1. Perform routine preventive maintenance, preliminary troubleshooting, and minor repair on aircraft communications equipment	3	--	--	--	--
2. Repair and replace communications antennas and feed systems .	3	--	--	--	--
3. Set and adjust transceivers in accordance with frequency plans .	3	--	--	--	--

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
1.0 Practical Factors - Continued					
4. Make receiver squelch adjustments	3	--	--	--	--
5. Measure receiver sensitivity and transmitter power output	--	--	--	--	2
6. Determine percentage of modulation of transmitters	--	--	--	--	2
7. Make transmitter and receiver frequency calibrations	--	--	--	--	2
8. Perform alignment and tracking adjustments of transceivers	--	--	--	--	2
2.0 Knowledge Factors					
1. Distress communications frequencies and procedures	--	--	--	--	2
2. Communications antenna theory.	--	--	--	--	1
3. Characteristics of induction field, radiation field, sky wave, ground wave, ground-reflected wave, ionospheric reflecting layers, skip distances, and maximum useable frequency and their effects on communications	--	--	--	--	C
F. AIRCRAFT RADAR EQUIPMENT MAINTENANCE					
1.0 Practical Factors					
1. Perform routine preventive maintenance, preliminary troubleshooting, and minor repair on aircraft radar equipment	--	3	--	3	--
2. Check performance of identification equipment installed in aircraft.	3	3	--	3	--
3. Energize radar equipment, set indicator controls, and adjust magnetron and crystal current	--	3	--	3	--
4. Measure system recovery time and determine minimum range	--	3	--	3	--
5. Measure and adjust low voltage power supplies	--	3	--	3	--
6. Adjust radar scope sweep length and sweep position; calibrate range marks	--	3	--	3	--
7. Install klystron tubes, make cavity and repeller adjustments, and adjust the automatic frequency control	--	--	--	--	2
8. Measure receiver sensitivity and transmitter power output	--	--	--	--	2
9. Test antenna stabilization and position control; adjust tilt control, azimuth drive, and limit control systems	--	--	--	--	2

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
1.0 Practical Factors - Continued					
10. Bench test and align identification equipment	--	--	--	--	2
11. Test transmitter pulse transformer, pulse forming network, and modulator; install magnetron and thyratron tubes	--	--	--	--	1
12. Perform spectrum analysis . . .	--	--	--	--	1
13. Measure ground position stabilization resolver response and check for correct solution to simulated relative motion problems.	--	--	--	--	1
2.0 Knowledge Factors					
1. Effects of various combinations of beam width, pulse length, pulse repetition frequency, scan rate, and power output relative to performance and applications of radar equipment.	--	--	--	--	C
G. AIRCRAFT ANTISUBMARINE EQUIPMENT MAINTENANCE					
1.0 Practical Factors					
1. Perform routine preventive maintenance, preliminary troubleshooting, and minor repair on aircraft antisubmarine equipment	--	--	3	--	--
2. Set channel frequencies, check, and adjust sonobuoy receivers . .	--	--	3	--	--
3. Install batteries and check sonobuoys	--	--	3	--	--
4. Check for proper operation and calibrate dipping sonar recorders	--	--	3	--	--
5. Test and replace dipping sonar transducers.	--	--	3	--	--
6. Make sensitivity tests and noise level measurements on MAD equipment.	--	--	3	--	--
7. Adjust servo gain and orient magnetometer of MAD equipment . . .	--	--	--	--	2
8. Align sonobuoy receivers.	--	--	--	--	2
2.0 Knowledge Factors					
1. Elementary physics of underwater sound	--	--	3	--	--
2. Method of perm compensation of aircraft for MAD installation . . .	--	--	--	--	2
3. Principles of MAD equipment compensation.	--	--	--	--	1

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
H. AIRCRAFT ECM EQUIPMENT MAINTENANCE					
1.0 Practical Factors					
1. Perform routine preventive maintenance, preliminary troubleshooting, and minor repair on ECM equipment	--	--	3	--	--
2. Calibrate pulse analyzers	--	--	3	--	--
3. Check crystal current of ECM tuners	--	--	3	--	--
4. Check and adjust ECM power supplies	--	--	3	--	--
5. Check and fill chaff dispensers . .	--	--	3	--	--
6. Check and adjust ECM tuners . . .	--	--	--	--	2
7. Bench test and align ECM equipment	--	--	--	--	2
8. Select and install ECM antennas .	--	--	--	--	2
2.0 Knowledge Factors					
1. Radar band and radio frequency classifications	--	--	3	--	--
I. THEORY AND PRINCIPLES					
1.0 Practical Factors					
None.					
2. Knowledge Factors					
1. Meaning of electrical and electronic terms and units of measure.	3	3	3	3	--
2. Function and characteristics of electronic circuit parts	3	3	3	3	--
3. Principles of electron tubes, semi-conductors, and transistors	3	3	3	3	--
4. Theory of a.c. and d.c. electricity and principles of magnetism . . .	3	3	3	3	--
5. Principles of rectifiers, filters, and regulators in power supply circuits.	3	3	3	3	--
6. Elementary physics of heat, light, sound, fluids, gases, and electricity.	3	3	3	3	--
7. Principles of basic machines . .	3	3	3	3	--
8. Principles of amplitude and frequency modulation.	3	3	3	3	--
9. Principles of electromagnetic induction and application to transformers, motors, and generators	3	3	3	3	--

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
2.0 Knowledge Factors - Continued					
10. Principles and applications of heterodyning	3	3	3	3	--
11. Principles and applications of synchros and servo systems . . .	3	3	3	3	--
12. Principles of detectors, amplifiers, and oscillators.	3	3	3	3	--
13. Principles of phase inverters and cathode followers	--	--	--	--	2
14. Principles of LCR differentiating and integrating circuits	--	--	--	--	2
15. Principles of pulse and pulse-time modulation	--	--	--	--	2
16. Types and characteristics of computing elements used to solve mathematical relationships. . . .	--	--	--	--	2
17. Principles and applications of gas filled and cathode ray tubes.	--	--	--	--	2
18. Principles of resonant circuits, coupling circuits, and filter networks	--	--	--	--	2
19. Principles of klystrons and magnetrons	--	--	--	--	2
20. Operating principles of direction and attitude sensing elements, including gyros, compasses, and accelerometers	--	--	--	--	1
21. Principles and applications of limiter, clamper, counter, and discriminator circuits	--	--	--	--	1
22. Principles of sweep generators, gated amplifiers, and timing circuits.	--	--	--	--	1
23. Micro-wave techniques and operating principles of wave guides, cavities, crystal mixers, and transmission lines	--	--	--	--	1
24. Principles and applications of saturable core reactors and magnetic amplifiers	--	--	--	--	1
25. Principles of impedance matching networks and devices .	--	--	--	--	1
26. Characteristics of readout methods used with analog and digital computing systems	--	--	--	--	C
27. Principles of infra-red detection	--	--	--	--	C
28. Operating principles of microwave antennas, dish reflectors, and associated RF feeds and parasitic reflectors and directors	--	--	--	--	C

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
J. TEST EQUIPMENT					
1.0 Practical Factors					
1. Select, use, and make minor repairs to test equipment used to measure voltage, current and resistance	3	3	3	3	--
2. Select, use, and make minor repairs to signal generators and oscilloscopes.	--	--	--	--	2
3. Analyze tests and measurements to be made on electronic equipment and determine most appropriate test equipment to use	--	--	--	--	1
4. Analyze test equipment defects and determine corrective action .	--	--	--	--	1
2.0 Knowledge Factors					
1. Theory and operating characteristics of basic electrical measuring instruments.	3	3	3	3	--
2. Types and applications of general purpose electronics test equipment	--	--	--	--	2
3. Circuit loading effects of test equipment.	--	--	--	--	2
4. Procedures for obtaining repair and calibration of test equipment.	--	--	--	--	1
5. Electronics test methods and practices	--	--	--	--	C
K. DRAWINGS, SCHEMATICS, AND PUBLICATIONS					
1.0 Practical Factors					
1. Use handbooks of maintenance and service instructions to locate and identify units of aircraft electronic equipment	3	3	3	3	--
2. Use electrical and electronic schematics to trace circuits. . . .	3	3	3	3	--
3. Follow pictorial diagrams and service instructions to disassemble, clean, and lubricate mechanical and electrical equipment	3	3	3	3	--
4. Use system block diagrams, data flow charts, and interconnection tables and diagrams in checking aircraft electronic equipment . . .	--	--	--	--	2
5. Use mechanical, electrical, electronic schematics and drawings in the installation of changes and modifications.	--	--	--	--	2

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
1.0 Practical Factors - Continued					
6. Complete electronics section of the Standard Aircraft Inventory Log on receipt or transfer of aircraft.	--	--	--	--	2
7. Interpret mechanical, electrical, and electronic schematics and drawings and make simplified versions	--	--	--	--	1
8. Use handbooks of maintenance and service instructions to determine performance specifications for making adjustments to aircraft electronic equipment.	--	--	--	--	1
2.0 Knowledge Factors					
1. Types and uses of information contained in handbooks of operating, service, and maintenance instructions.	3	3	3	3	--
2. Types and purposes of information found in electronics material bulletins and changes	--	--	--	--	2
L. AIRBORNE CIC OPERATION					
1.0 Practical Factors					
1. Operate airborne CIC radar equipment and remote indicators	--	--	--	3	--
2. Identify, classify, and track radar targets and report altitude, range, bearing, and relative motion and speed.	--	--	--	3	--
3. Maintain airborne CIC status boards and plots.	--	--	--	3	--
4. Operate airborne CIC voice communications equipment	--	--	--	3	--
5. Solve maneuvering board problems for course and speed, closest point of approach, and maneuvering to new position	--	--	--	3	--
2.0 Knowledge Factors					
1. Sea-air rescue procedures.	--	--	--	3	--
M. AIRBORNE CIC NAVIGATION					
1.0 Practical Factors					
1. Convert given positions into grid coordinates and transfer between different scales	--	--	--	3	--

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
1.0 Practical Factors - Continued					
2. Use dead-reckoning navigation to determine headings, drift, speed, time, and track; set and operate DRT.	--	--	--	3	--
3. Make performance checks and operational adjustments of navigational computers	--	--	--	3	--
4. Identify radar land targets, compare to charts, and provide navigational and landing approach information	--	--	--	3	--
5. Operate airborne ECM equipment to detect electromagnetic signals and obtain bearings and identify characteristics of signals	--	--	--	3	--
2.0 Knowledge Factors					
1. Interrelationship of airborne and and shipboard CIC operations . . .	--	--	--	3	--
N. ADMINISTRATION					
1.0 Practical Factors					
1. Identify electronics parts by nomenclature and stock number and prepare supply requisition to obtain replacement	--	--	--	--	1
2. Use NAVAER Publications Index to locate, identify, and obtain technical publications, directives and manuals	--	--	--	--	1
3. Identify and order tools, equipment, and material.	--	--	--	--	1
4. Maintain custody records and conduct inventories.	--	--	--	--	1
5. Supervise the use, filing, and maintenance of publications, logs, and records.	--	--	--	--	C
6. Organize and supervise facilities for repair and maintenance of aircraft electronic equipment . . .	--	--	--	--	C
7. Maintain aircraft electronics configuration and status records . . .	--	--	--	--	C
8. Supervise inspection procedures to insure that applicable technical specifications and standards of workmanship are met	--	--	--	--	C
2.0 Knowledge Factors					
1. Standard organization and maintenance procedures of aircraft squadrons and maintenance activities.	--	--	--	--	1

Qualifications for Advancement in Rating	Applicable Rates				
	ATN	ATR	ATS	ATW	AT
2.0 Knowledge Factors - Continued					
2. Types of purposes of FUR's....	--	--	--	--	1
3. Types of information contained in aeronautical technical publications pertaining to aircraft electronic material and equipment ..	--	--	--	--	1
4. Interpretation of source codes in parts catalogs	--	--	--	--	C
5. Procedures for surveying accountable materials	--	--	--	--	C

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